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THE SUPPLY OF MUNITIONS

PART I

TRENCH WARFARE SUPPLIES

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CHAPTER I.

INTRODUCTORY.

British and German estimates as to the value of trench warfare weapons, based on the experiences of the Russo-Japanese War, differed very considerably previous to the outbreak of hostilities in 1914. Relying upon rapid and accurate rifle fire, British training books laid it down that infantry warfare would begin at from 1,200-1,500 yards, and that the battle would be in full progress at 800-1,000 yards, reaching a decisive point at 400-500 yards. Reports on the trench warfare conditions which prevailed at the siege of Port Arthur in 1904 led to the development of a single British service grenade, of which about a dozen only had been made shortly before the outbreak of war.[1] No British pattern of a trench mortar existed. Official knowledge of the production and use of mortars was extremely limited. Relatively few British soldiers had been trained to throw grenades ; none at all to use trench mortars. On the other hand, grenades were a standard issue in the German army before the war. Service patterns of trench mortars or *minenwerfer* had been developed. Discussion as to methods of making these weapons was almost a commonplace in German engineering journals.

The conditions of warfare established on the Western front as soon as the first German advance had been checked at once emphasised the need for trench weapons. The high velocity fire from machine guns and rifles became so deadly that the troops were forced to dig themselves in, and inevitably lost the proper field of fire for a rifle. Some form of high angle fire at a comparatively short range became necessary. This was provided by trench howitzers and grenades. Other miscellaneous stores were introduced to meet the new conditions of siege warfare.

The narrative which follows is an attempt to describe the formidable difficulties experienced in equipping growing armies with weapons of an absolutely novel class, and to give a general idea of the methods which were used in organising their supply.

I. Characteristics of the Demand.

The ordinary difficulty of effecting a satisfactory relation between the current production of munitions and the needs of the army in the field attains exceptional proportions in the case of novel stores. The formulation of the demand for supplies to meet the unforeseen conditions of siege warfare which faced the British Army after the battle of the Aisne presented a serious problem. It was equally difficult to

[1] Hist Rec./H/1600/14, p. 37.

arrange for the production in large quantities of entirely novel stores, undefined in character and subject to constant changes in nature or quantity.

The earliest demands made by the Army were necessarily indefinite. The first request for trench mortars was couched in general terms. Sir John French asked for "some special form of artillery . . . which can be used with effect at close range in the trenches," laying down general desiderata only.[1] Similarly, in asking for a certain type of hand grenade, Major-General Rawlinson stated early in December,[2] 1914, that "this trench warfare in which we are now engaged is causing a demand for all sorts of things which are not recognised by regulation."[3] Again, a requirement for definite fixed numbers of three kinds of hand grenade, forwarded from General Headquarters to the War Office on 20 May, 1915, was supplemented a month later by a request for "the supply of any type available in as large quantities as possible," pending issue of the desired patterns.[4]

It rested with the home authorities to translate these indefinite requests into a practical programme of supply. The Master-General of Ordnance, in giving instructions for the provision of an increased supply of hand grenades and trench mortar ammunition on 30 May, 1915, fixed a daily rate of production, at the same time stating that "we cannot have too much."[5] While at this time specific demands were received for trench mortars and a ration of ammunition, it was still stated that the number of mortars must depend upon the output of bombs.[6] Hence no very firm basis existed for a manufacturing programme either of ammunition or mortars. In October, 1915, an effort was made by the supply authorities to obtain definite instructions as to the ration for each mortar and to secure greater regularity in the demand for grenades.[7] Accordingly, the number of rounds to be allowed respectively to light, medium and heavy mortars was fixed by General Headquarters, France, on 27 October, 1915, and thenceforward requirements for the more common trench warfare stores were formulated into a more systematic programme on a divisional basis.

The indefiniteness of the demand tended to decrease with the prolongation of the new type of warfare; but constant fluctuations in quantity and nature remained an outstanding characteristic in the programme for trench warfare stores. A notable instance is that of the Mills grenade. The demand in July, 1915, was for 500,000 weekly. This number was subsequently increased to 703,000, but in January,

[1] 121/Stores/436.

[2] The exact date does not occur. It was before 12 December.

[3] 75/3/2486.

[4] T.W. 2180.

[5] Hist. Rec./R/1600/7.

[6] M.G.O. to M. of M., 24/6/15 (D.M.R.S. 262).

[7] T.W. 2104; Mr. Roger to Dr. Addison, 19/10/15 (C.R./T.W.D./1121); D.M.R.S. 262.

1916, it was reduced to 250,000. Six months later it rose again to 1,000,000, and in August to 1,400,000. In the following December the demand suddenly dropped to 750,000 weekly, a stock of four millions being required in reserve. Military authorities considered that these fluctuations were the inevitable result of changing circumstances in the field, and were to be regarded as " a normal feature of the war because of unexpected conditions."[1]

Novel demands arising from tactical developments were of considerable urgency, delivery being required by a fixed date for some special operation. Thus General Headquarters, France, telegraphed on 22 August, 1915, for Stokes mortars with smoke ammunition, which were to be delivered within ten days, when as yet neither the mortars nor their ammunition existed. This demand was only met by extraordinary action, by close intercommunication between the supply authority and the First Army, which needed the smoke screen for its operations in the coming offensive, by the improvisation of a pattern, the issue of unproved stores, and by the completion of manufacturing processes in the army workshops.[2]

The production of a new store which should reach the high standards of efficiency and safety demanded by British military authorities was necessarily a very slow process. It was further hampered by the need for building up an enormous manufacturing capacity for articles never before produced in the country. Yet, at the inception of trench warfare, the demand was for the immediate delivery of large quantities. Since no stocks existed, troops were driven to improvise in the field weapons of which the danger was notorious and the efficiency doubtful. The general course of action during the first year of trench warfare was to send out any type of weapon readily manufactured in large quantities while a satisfactory design was in course of development. This practice was voiced by the Master-General of the Ordnance in December, 1914, when he wrote, *apropos* of General Rawlinson's request for French grenades: " They appear to be most dangerous, but still we must give them what they ask for."[3] Jam-pot and Hairbrush grenades, resembling the weapons improvised in the field, were sent out late in 1914. Ball and Pitcher grenades were produced in large quantities between July and November, 1915, while the production of safer and more efficient patterns was in course of development.[4] Miscellaneous mechanical weapons comparatively simple to manufacture, such as catapults and spring guns, were issued to the Army while the country's production of trench mortars was being built up. Seven different service types of trench mortar had been brought into existence by May, 1916, when manufacture had become fully organised and patterns comparatively settled.

The main disadvantage of this system was the issue of widely varying types of stores to forces unaccustomed to the use of any weapon

[1] D.M.R.S. 262.
[2] HIST. REC./R/1610/4; D.M.R.S. 252.
[3] 75/3/2486.
[4] T.W. 5729.

of the kind. Multiplicity of patterns was particularly undesirable when the instruction of the troops in their use was proceeding *pari passu* with the development of the weapons themselves. Accordingly, when the first urgency was past, the Army began to emphasise the desirability of reducing the number of types of trench warfare supplies, basing their new demands upon experience gained with the various patterns in the field. The diversity of grenades was diminished by the abandonment of emergency types in the autumn of 1915, and by a decision taken in February, 1916, to rely upon time-fused hand grenades only. The seven types of mortar in service use were decreased to three only in the following May.

With a few exceptions, later changes in design were in the nature of improvements on the standard types. By the last year of the war it was considered that these modifications did not seriously exceed in number the normal changes in the pattern of standardised munitions.[1]

II. The Nature of Trench Warfare Stores.

The novel and experimental nature of trench warfare stores was in fact a temporary phenomenon entirely due to the unexpected development of the war of positions which began in November, 1914. Other distinctions between these supplies and the main body of service munitions were of a more durable kind. The mortar is a short-range weapon of low velocity. It is generally smooth-bored, and is always fired at gas pressures even lower than those of a shot-gun. It is therefore simple in pattern, use and manufacture as compared either with the rifle or with the complex and highly-finished weapons of the artillerist. Bombs and grenades are far less complicated missiles than shells. Their design and production are governed by fewer limiting factors. In consequence the conditions affecting production allow of far greater ease in providing manufacturing capacity, far more diversity in the material utilised, and far less skill in the labour employed in making trench warfare weapons than in making guns and shells.

This distinction impressed itself most strongly upon the supply authorities, whose interests lay in rapid and economical manufacture. Artillerists during the early part of the war regarded the mortar as a miniature heavy howitzer, classing together as ordnance all weapons in which an explosive propellant was used, all missiles with a high explosive charge. Eventually, however, it was more generally recognised that the development of mortars as a distinct class of munitions had certain well-defined advantages. It allowed free play to their characteristics, viz., speed of production, economy of money, material and labour in construction at home, and the use of less-skilled personnel in the field both for manning the weapons and for executing repairs in the army workshops.

[1] M.C. 670.

Other stores peculiar to trench warfare, notably trench diggers and portable entanglements, were more closely related to engineering apparatus. Others were the personal equipment of the soldier, such as his helmet or body armour. Again, miscellaneous stores were to be provided for life in the trench. Such were rifle rests and the strombos horns, rattles or triangles to be used as gas alarms. In fact, apart from trench ordnance, a great diversity characterised the stores generally known as "trench warfare supplies."

From a mere accident of departmental organisation and chiefly by reason of a common novelty in their use, the term "trench warfare supplies" under the Ministry of Munitions was extended to include munitions whose connection with the war of position was slight or only temporary. Such were chemical warfare supplies, fireworks and certain classes of transport, *e.g.*, the Telpher railway. As far as possible it is proposed to eliminate these from the following account which relates only the story of trench warfare supplies in the limited sense of the phrase.

CHAPTER II.

MANUFACTURE ALONGSIDE DESIGN.

I. The Position in July, 1915.

When the Ministry of Munitions became entirely responsible for the supply of trench warfare stores in July, 1915, the efforts already made by the War Office had as yet failed to meet adequately a demand which had started from zero in October, 1914, and had advanced steadily out of all proportion to the arrangements made for immediate production. The work already carried out had included the development of several patterns of trench mortars. These varied in efficiency, but were all subject to the same limitations. The production of the mortars depended upon the capacity for supplying ammunition. This in its turn had invariably been restricted within extremely narrow limits by the use of complex components which were required more urgently for other purposes. The patterns still remained unsettled, and it was therefore a definite policy to restrict their manufacture to the Ordnance Factories, where the work was executed in competition with the better-known and firmly established manufacture of guns and gun ammunition. Some slight relief had been obtained by sub-letting the easier parts of bomb manufacture ; but this in itself only enhanced the problem of balancing the output of ammunition with that of its complex components. Very similar difficulties were being experienced by the one armament firm which was producing trench mortars and their ammunition. The only commercial source of supply which had as yet been tapped was one explosive firm which was employed in making one of the least efficient types of bomb.

The position in regard to grenades was scarcely easier, although the future outlook was rendered brighter by the existence of an efficient hand grenade which could be readily manufactured. Deliveries of this grenade were already coming forward and a scheme for obtaining it by group manufacture among commercial firms was in course of organisation. The supply of the other service patterns was hampered by much the same conditions as that of trench mortar ammunition. The designs were not such that they could be immediately produced in large quantities. Great difficulty had been experienced in obtaining from the monopolists of the one known pattern of rifle grenade the information which would enable manufacturing capacity to be increased. A slight advance only had been made in establishing competition with this firm, whose deliveries were entirely inadequate.

In the meantime the armies had been making their own mortars, bombs and grenades, and these were being supplemented at home by the issue of stopgap stores, such as catapults, spring guns,

and time-fused grenades, which were simply made, but of inferior efficiency and safety. These had served to meet some small part of the demand for trench weapons which increased enormously as the campaigns of 1915 revealed more clearly the need for the new types of stores. It is intended to consider in this chapter the general methods used by the Ministry of Munitions in solving the problems outlined above, and in the chapters which follow to outline the results achieved in the case of particular weapons.

II. Organisation and Procedure.

The administrative organisation for supplying these novel stores had an extremely intimate connection with the results obtained, and reflected clearly the various phases through which purely experimental production passed into comparatively standardised manufacture.

(a) War Office Organisation for the Supply of Trench Weapons.

In October, 1914, when the permanence of trench warfare first became an established fact, the supply organisation of the War Office was arranged according to the different branches of the military service, and no separate body existed for the sole purpose of producing novel stores as such. The importance of an adequate supply of modern weapons had not yet been fully realised. Responsibility for the provision of the supplies peculiar to the new method of warfare was not strictly defined. The Directorate of Artillery controlled the provision of trench mortars, their ammunition, and the service hand and rifle grenades. On the other hand, engineers alone had been trained in the use of hand grenades since the Russo-Japanese War, and the Engineer-in-Chief referred to the Directorate of Fortification and Works questions relating to these and also to contrivances for use in the trenches, *e.g.*, boring apparatus or "pumps for projecting flame." Such points had generally been submitted to Colonel, afterwards General, Sir Louis, Jackson, who then controlled the coast defence section of the Directorate of Fortification and Works and had made a special study of field defence and siege work.[1] By special arrangement with the Master-General of the Ordnance, he was authorised to design and produce emergency grenades to supplement the service types supplied under control of the Director of Artillery.[2] On 3 December, 1914, the Engineer-in-Chief had consulted him as to the production of "stink bombs."[3] Later, his duties had been extended to cover the design and supply of chemicals, irritant and lethal, and of suitable containers in the form of cylinders, hand grenades or other missiles, together with mechanical engines for their propulsion, such as the Leach catapult, the West spring gun, and pneumatic guns.

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[1] Hist. Rec./R/1600/18; Hist. Rec./H/1600/8.

[2] Hist. Rec./H/1600/8.

[3] Hist. Rec./R/1600/18.

During the spring of 1915, Colonel Jackson's subsection had become entirely occupied with these novel stores and had taken the name of F.W. 3a or "Engineer Munitions Branch." The staff was strengthened by the appointment of certain civilians. On 28 May, 1915, the Engineer Munitions branch had moved from the War Office to Storey's Gate, taking with it its own contracts officer. A considerable degree of autonomy had thus been obtained. Special procedure was adopted to secure close control by the section over the production and issue of novel stores. The rapid development anticipated in the production of trench warfare stores threatened to congest traffic at Woolwich. Accordingly a system of direct issues overseas was initiated by officers of the branch on 12 June, 1915, in conference with Director of Ordnance Stores E.F. and the Deputy-Director of Equipment and Ordnance Stores.[1] This arrangement was formally confirmed in the following July.[2] It entailed inspection at works instead of at Woolwich.[3] Additional staff brought into the branch in June, 1915, included engineers styled "inspectors," whose duty it was to find sources of supply and hasten production, as well as to test the quality of deliveries.[4]

(*b*) Formation of a Trench Warfare Department under the Ministry.

During the summer of 1915 Colonel Jackson was developing a scheme for the production of a "stream of explosive incendiary and chemical missiles" to be thrown from bomb engines by day and night in order to maintain constant offensive action in the trenches.[5] His section was transferred to the Ministry of Munitions on 23 June, 1915, being styled the Trench Warfare department, while he himself was appointed director-general, with a financial adviser, Mr. Alexander Roger. The new department took over responsibility for the supply of trench mortars and their ammunition and of service grenades, as well as the special stores with which General Jackson had been dealing. The choice and development of patterns for mortars, bombs and service grenades remained with the Director of Artillery, advised by the Ordnance Board.

In respect to the special novel munitions under his control, General Jackson's functions considerably exceeded those which were transferred from the Army Council to the Minister at this time. They included responsibility for patterns, since the Army Council considered it impracticable to separate design from supply in the case of experimental stores. The establishment of training schools at Clapham and elsewhere under his administration gave him a certain responsibility for instruction in the use of novel weapons which the Minister did not possess in regard to other stores. The system of

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1 Q.M.G. 10/7694.
2 T.W. 659, 1023, 3384.
3 T.W. 245.
4 Hist. Rec./H/1600/11.
5 Hist. Rec./R/1600/19.

direct issue overseas was maintained, although it exceeded the duties of the Minister towards munitions generally as defined 5 June, 1915.[1]

(c) RELATIONS WITH THE ARMY IN THE FIELD.

The exceptional responsibility of the Trench Warfare department for the issue of stores and the systematic intercommunication already existing between General Jackson and the armies in France, particularly in respect to chemical supplies, resulted in a far closer contact with the forces in the field than was usual in other supply departments. It was generally maintained by the Trench Warfare department that direct intercourse with the headquarters of the Expeditionary Force was particularly essential to the efficient supply of experimental stores. In July, 1915, they urged the need for close personal touch between their department and the front as a means of ensuring that the stores ultimately produced should be of the type required, referring particularly to the demand recently received for any form of a grenade available pending manufacture of approved patterns. Accordingly Dr. Addison, the Parliamentary Secretary concerned, approached the War Office with a request for systematic interchange of visits between supply officers and the front.[2] At the same time it was agreed in conference that the exact extent of the researches to be carried out by General Jackson, "with a view to providing for the adequate supply of approved patterns," was a matter for the Minister to decide.[3]

During the next six months the distinct procedure thus established in regard to trench warfare stores was widely interpreted by General Jackson's department. Orders were placed for the types of trench mortars production of which was practicable rather than those for which formal demands had been received.[4] The smoke ammunition for the battle of Loos was improvised in close collaboration with the First Army, which itself provided components such as friction tubes, the Army Council having repudiated any responsibility in respect of these stores.[5] By such action the urgent and immediate needs of the troops were met on special occasions when the lack of approved patterns capable of speedy production threatened to prevent any supply by normal methods. The disadvantages inherent in the irregularity of this procedure were, however, pointed out by the Director of Artillery on 20 October, 1915. In response to a direct request from France, the Trench Warfare department had issued overseas smoke ammunition similar to that previously supplied, and without the components formerly provided by the First Army, lack of which rendered the ammunition useless. The centralisation of control over requirement was threatened by direct communications between the

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[1] *Transfer of Functions, etc.*, Part I.; M.W. 1374.

[2] T.W. 442.

[3] 1/Gen. No./1557.

[4] D.M.R.S. 252; T.W. 2172/1.

[5] Gen. Jackson to D.M.R.S., 8/11/15 (D.M.R.S. 252); Lieut. Leeming's Report, 13/9/15.

department and General Headquarters, Mediterranean, in regard to trench mortars and other stores for the Dardanelles.[1] The department itself was experiencing difficulties due to the informal nature of the procedure. For example, it was found impossible to get delivery instructions for certain catapults, or to locate West spring guns in order to issue spare parts.[2]

The representations of the Director of Artillery were followed on 21 October, 1915, by a formal notification from the Army Council to the Minister that the direct communication existing between General Headquarters, Mediterranean, and the Trench Warfare Supply department contravened the general arrangements whereby the determination of military requirements and the consideration of suggestions as to new types of war material were functions of the Army Council. While the Minister agreed on 22 November, 1915, that such proposals should be submitted to the Army Council, he maintained the desirability of interchange of information between the producers and the users of munitions, particularly in the case of trench warfare supplies, which were nearly all experimental. Provision was thereupon made for visits from the officers of the Ministry to the armies in France.[3] About the same time it was arranged that the exceptional procedure in issuing trench warfare stores against unauthorised demands should be restricted to supplies for the Special Companies,[4] and thenceforward the normal procedure was established in notifying requirements for all trench warfare stores other than these.

(*d*) Development of the Organisation for Research and Design.

The changes in procedure described above were practically contemporaneous with the transference to the Ministry of Munitions of control over the design and approval of munitions in general. General Du Cane was appointed Director-General of Munitions Design on 3 December, 1915. On 20 December the Trench Warfare department was divided into two distinct branches. The one under General Jackson dealt with research and experiment as to trench warfare, chemical and other novel stores such as fireworks; the other, under Mr., afterwards Sir Alexander, Roger, became responsible for the supply of the same munitions. During the next six months General Jackson's branch was gradually absorbed into the Department of Munitions Design, within which two other sections also exercised the duties of a design officer in respect to the same stores. One of these combined responsibility for the pattern of trench mortars and their ammunition with a similar function towards ordnance and shells; the other dealt with grenades, body armour and other trench warfare supplies as well as small arms. Very little *liaison* existed between any of these design bodies and the supply department. The research authority

[1] D.M.R.S. 252.
[2] T.W. 123, 2598.
[3] D.M.R.S. 252.
[4] T.W. 3042; D.M.R.S. 268.

lost the benefits arising from close supervision of experimental manufacture,[1] while the supply authority gained little of that direct knowledge of the behaviour of weapons in the field which had previously been accepted as essential to the efficient production of novel munitions.

These disadvantages were redressed by a reorganisation which took place in 1917. In February a "Trench Warfare Committee" was established solely to consider the design of trench mortars, grenades and body armour, and a Superintendent of Trench Warfare Design reporting to Director-General of Munitions Design was housed with the supply department. In October, 1917, the Trench Warfare Research department ceased to exist, its chemical investigations passing to the newly established Chemical Warfare department.[2] Responsibility for the design of trench warfare stores proper was transferred to a Trench Warfare (Design) department, which absorbed the functions of the Trench Warfare Committee. The new design department was housed in the same building as the supply department. Close touch was further ensured by the appointment of supply officers as *ex-officio* members of its advisory committee, on the ground that the position of supply was the measure of the cloth to which the coat had ultimately to be cut, and its importance, therefore, came next only to considerations of safety.[3] The department was controlled by Major-General G. T. M. Bridges, C.M.G., D.S.O., and subsequently by Brigadier-General A. M. Asquith, D.S.O., and its staff included other officers who had taken a prominent part in the work of the trench mortar schools and of army workshops in France and were thus familiar with actual conditions in the field. The rapidity with which this system worked is well illustrated by the adoption and production of the Livens projector, which will be narrated below.[4] The advantages experienced from this system of *liaison* with the forces in the field were so considerable that a similar form of organisation was subsequently applied to other departments concerned with stores of unstable design by the creation of the Tank Board and the Chemical Warfare Committee in 1918.[5]

(e) DEVELOPMENT OF THE SUPPLY DEPARTMENT.

The original separation of supply from design in December, 1915, had been made on representations from Mr. Roger that the work of supply was seriously hampered by its subordination to research.[6] Until that date supply had been carried out in a number of loosely-knit sections, each concerned with the development, production and issue of a store complete as to all its components and accessories. The system was intended to concentrate responsibility in individuals in order to obtain to the full the benefit of their energy and experience in a time of emergency and to secure entire control over production

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1 Gen. Jackson to Dr. Addison, 6/4/16.

2 HIST. REC./H/1650/8.

3 Estab. Cent. 53/47.

4 Chap. V.

5 Estab. Cent. 1/267.

6 HIST. REC./R/1600/2.

in the experimental stage. In order to cope effectively with constant changes in design, responsibility for every part of these novel weapons was concentrated. Thus a single section dealt with a certain type of mortar and all the details of its ammunition, whereas the organisation of the central body of the Ministry severed the responsibility for supply of the standardised gun from that of the shell.

The Outside Engineering branch, originating in the inspectors appointed by Colonel Jackson in June, 1915, provided a staff of local officers which reported to headquarters and rendered the supply officers independent of the area organisation established for the main body of the Ministry. In this respect, as well as in the arrangement of function by the uses to which a store was put rather than by the nature of the store itself, the organisation of the Trench Warfare Supply department cut across that of the Ministry as a whole. The distinct characteristics of the department were further emphasised by the practical independence of the heads of its sections.[1]

These anomalies disappeared gradually with the reduction of urgency by organised production and the building up of stocks. The semblance, at least, of conformity with the general scheme for area organisation was attained by the housing of Trench Warfare outside engineers in the local area offices. Supply officers entered into a provisional engagement to place 80 per cent. of their contracts through boards of management on 17 December, 1915. Uniformity of action was attained within the department by the establishment of common services for transport, finance, proof and inspection.[2] The gradual accumulation of all duties relating to the filling and storage of trench warfare munitions in the hands of a single section was completed by 28 April, 1917, and tended to the same end. Uniformity of policy with the main body of the Ministry developed simultaneously. The appointment of common service officers for finance and inspection was a step in this direction, since these officers reported to the authorities who were responsible for their respective duties throughout the Ministry.[3] The gradual reorganisation of the department was rounded off by the constitution of the Trench Warfare (Design) department in October, 1917. Scarcely had it been completed when the absorption of the various functions of the Trench Warfare Supply department by corresponding branches of the main body of the Ministry began to take place.

(*f*) Disintegration of the Trench Warfare Supply Department.[4]

In October, 1917, responsibility for the design of stores for chemical warfare had been separated from design duties relating to trench warfare supplies. In the following April the transfer of supply duties towards chemical warfare stores from the Trench Warfare Supply

[1] Hist. Rec./R/263/6/4; C.R. 2931.

[2] C.R./T.W.D./1117 (3).

[3] C.R./T.W.D./1117 (11).

[4] Based on M.C. 646, 670.

department left that department responsible only for trench warfare stores proper and for certain other supplies undertaken on account of their novel and experimental nature, the chief being aircraft bombs, fireworks, the Telpher railway, and mine supplies for the Admiralty.

Upon the formation of the Munitions Council in August, 1917, it had been arranged that the Controller of Trench Warfare Supply (Mr. E. V. Haigh) should report on each store to the corresponding council member. Thus questions relating to mortars were referred to the Council Member for Guns, those touching trench mortar ammunition to the Council Member for Projectiles.[1] In the following April it was decided to disperse the various sections of the Trench Warfare Supply department among the corresponding sections of the main departments for supply of standardised stores, on the ground that trench warfare supplies had passed the purely experimental stage and that the reduction in the general munitions programme and the need for economy of material and money rendered a concentration of administrative staff and control over capacity and material particularly desirable.

In making this decision the Minister (Mr. Churchill) ruled that provision against the undue standardisation of trench warfare weapons should be made by strengthening the department responsible for design, so that it should have wider experimental facilities and ample plant.[2] Accordingly in June, 1918, a special supply section was added to the Trench Warfare (Design) department from the headquarters staff of the Outside Engineering branch. Members of this staff were at this time chiefly engaged on experimental work in connection with the Telpher railway, while their general functions had already been absorbed in the newly-formed Central Engineering department. The scope of the design department's work was considerably extended in August, 1918, when a sub-committee was formed to consider on improvements to existing service stores used in trench warfare, and also to devise new stores to meet anticipated requirements in the field.[3]

The actual absorption of the Trench Warfare Supply department by the departments responsible for production of standardised munitions took place gradually. It was practically complete by July, 1918.

III. Methods Adopted by the Trench Warfare Supply Department.

(a) Reliance upon Capacity outside the Sources of Ordnance Supply.

The main feature in the practice adopted by the Trench Warfare (Supply) department was a consistent avoidance of any encroachment upon the skilled labour and highly specialised machinery needed for

[1] Hist. Rec./R/263. 01/10.

[2] M.C. 646.

[3] Hist. Rec./H/1600/14, VI. 1.

producing guns and shells.[1] The War Office had at first relied entirely upon the Ordnance Factory and the armament firms to develop designs for trench warfare weapons and to produce trench mortars, bombs and grenades. Congestion of ordnance work and the urgent circumstances of the time had led to certain changes in this practice during the first six months of 1915. Sub-contracts for bombs had been placed with fresh firms by the Chief Superintendent Ordnance Factories; attempts had been made to spread the sources of grenade supply; the beginnings of a scheme for subdividing grenade production were in hand.[2] The Trench Warfare (Supply) department converted these new practices into a definite and systematic policy. Large orders for the Ordnance Factory pattern of medium mortar (the 2-in.) were placed with railway repair shops, agricultural machinery makers, and various Sheffield firms, none of which was acquainted with gun manufacture.[3] The cast-iron bomb-heads for this mortar were obtained from practically all the leading iron foundries and numerous smaller foundries.[4] The proportion of production of trench mortars and their ammunition by the trade was increased as the year 1915 went on, although certain types of mortar were made rapidly by the Ordnance Factory during the autumn, and, owing to a change in design, the Royal Laboratory remained the sole producer of 4-in. ammunition until April, 1916.[5] Similarly, grenade contracts were spread among cotton machinery makers and numerous comparatively small firms chosen by the director of the outside engineers from personal knowledge.[6] The small fireworks firms of Yorkshire were persuaded to undertake grenade filling in July, 1915, and began work at once. The Ordnance Factory was gradually relieved of its responsibility for loading trench mortar ammunition by the erection of filling stations for the trade-made bombs, the first of which began output in October, 1915. In 1916 the reduction in the types of trench mortar eliminated the only one produced by an armament firm, the 1·57-in., and two others, the 4-in. and 3·7-in., supplied mainly by the Ordnance Factory. By the end of the year 1916 all work upon mortars and their ammunition had been withdrawn from Woolwich. Moreover, in February, 1916, simpler types of fuse had been substituted in 2-in. ammunition for the existing pattern, which was the No. 31 modified from the No. 80, a complex fuse urgently needed for artillery purposes. Thus output of medium mortar ammunition no longer depended upon the surplus production of an essential component by skilled firms after artillery needs had been satisfied.[7] An important departure from the practice of avoiding ordnance capacity was, however, made under less urgent conditions in February, 1917, when a large order for complete 6-in. mortar barrels was placed with Messrs. Hadfield's, of Sheffield.

[1] HIST. REC./H/1600/7, p. 5; *ibid.*, 1600/11, p. 12.
[2] HIST. REC./H/1600/13.
[3] T.W. 1963; HIST. REC./H/1600/7.
[4] HIST. REC./H/1610/2, p. 4.
[5] HIST. REC./H/1610/16.
[6] HIST. REC./H/1600/11, p. 3.
[7] HIST. REC./H/1630/2, p. 3.

(*b*) ADOPTION OF TYPES TO SUIT THIS POLICY.

In certain instances the practice of utilising capacity outside that required for ordnance was carried so far as to effect a change in the demand. The War Office requirement in August, 1915, was for 500 Vickers mortars and 500 2-in. mortars,[1] but the weapons supplied were 800 2-in. and 200 Vickers.[2] Still more remarkable was the action taken by the Ministry in supplying an entirely new kind of light mortar—the 3-in. and 4-in. Stokes mortars—which was adopted with the main idea of opening up new sources of supply.[3] The adoption of this mortar had been negatived in the previous April in view of the existence of satisfactory types,[4] although it was considered that the Stokes mortar as it then existed could be developed into an efficient weapon.[5] The service light mortars were then the 3·7-in. and the 4-in., output of which was restricted to the Ordnance Factory.[6] Mr. Lloyd George emphasised the importance attached by the new department to conditions making for the rapid expansion of supply by sanctioning the production of 1,000 Stokes mortars, with corresponding ammunition, provisionally on 30 June, 1915,[7] and finally on 12 August, 1915,[8] in anticipation of any specific demand. Production of the Stokes mortar and its ammunition was confined to the trade. The barrels were obtained from the Mannesmann Tube Company by a comparatively simple process saving about 75 per cent. of the time and labour usually taken in gun-forging.[9] The ammunition was supplied by numerous small general shops such as motor-garages throughout the country[10] and loaded at an agency factory managed by the British Westfalite Company, makers of commercial explosives.

(*c*) MODIFICATIONS IN DESIGN TO FACILITATE MANUFACTURE.

The decision to restrict the production of trench warfare supplies to commercial firms, together with the original tendency of the supply department to subordinate all other issues to rapidity of output, gave special importance to the modification of patterns with a view to facilitating manufacture. Apart from the adoption of entirely different types for the purpose of expediting supply, many changes were made in patterns and material to facilitate production by makers unaccustomed to armament work and lacking the skilled labour and special machinery needed for gun or shell production. Several

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1 D.M.R.S. 252.
2 *Ibid.*
3 *Ordnance Board Minutes*, 13610 ; HIST. REC./H/1610/5.
4 *Ordnance Board Minutes*, 13686.
5 *Ibid.*, 13610.
6 HIST. REC./H/1600/13.
7 C.R./T.W.D./1119 (1).
8 *Ibid.* (7).
9 HIST. REC./H/1600/11.
10 *Ibid.*, 1610/6, p. 4.

noteworthy changes were introduced for this purpose during the latter half of 1915. Two of these may be cited in illustration. The supply of 2-in. bombs by the trade was only effected by substituting a hot-drawn tubing evolved after considerable experiment for the cold-drawn steel almost approaching tool-steel which was originally specified for the bomb stem, and could only be obtained by encroaching upon a limited capacity devoted to the naval and railway services.[1] During the autumn of 1915, when the supply of components was a limiting factor in the output of mortar ammunition, the exploder of the 2-in. bomb was redesigned to use a commercial detonator No. 8, for which plant existed, in place of the detonator specified in the R.L. design, for which the available capacity was inadequate. By this means output was greatly facilitated, and a delay of several months which would otherwise have occurred in erecting special machinery was avoided.[2]

(*d*) Manufacture pending Approval.

So long as no reserve existed and the demand for trench warfare stores was particularly urgent, the emergencies of the time were held to justify production by abnormal methods which were difficult to defend in principle. The efficiency and safety of standardised stores issued to the troops was normally safeguarded by a well-defined procedure which prevented production previous to the issue of sealed drawings to a duly approved design, and provided for systematic inspection to ensure that manufacture had been to the exact pattern. While design and inspection authorities represented that the need for testing safety and efficiency was particularly apparent in the case of novel and untried stores, supply officers upon whom rested the responsibility for the actual output of trench warfare munitions adopted under the stress of circumstances methods which contravened the accepted procedure. Thus, in view of the congestion of work in the inspection department at Woolwich during the summer of 1915, the Trench Warfare Supply department set up its own drawing office, issued its own drawings to contractors, and during the first urgent six months of its existence inspected most of its own stores by means of its outside engineers. Accordingly it became possible to make and issue in large numbers emergency weapons, such as the Ball grenades intended partly to meet the immediate needs of the Mediterranean army in 1915, and the 4-in. Stokes mortar with smoke ammunition hurriedly produced for the Battle of Loos in the following September. Similarly, with the sole intention of avoiding delay, manufacture of the 3-in. Stokes mortar ammunition was put in hand before the design had reached its final form. It was reported as to this action about 4 December, 1915, that " although such a procedure is indefensible in principle, and in practice caused much worry and

[1] *Ordnance Board Minutes*, 15591, 16136, 16279, 17285.

[2] Hist. Rec./H/1600/7; Unregd. Memo. Technical Adviser, T.W.S.D. No. 19; T.W. 2050.

trouble both to manufacturers and to the department, there is no doubt whatever that the production has been considerably accelerated thereby, and the extra cost has been quite inconsiderable."[1] Where the introduction of a novel weapon involved the building up of an entirely new class of manufacturing capacity, a considerable amount of anticipatory preparation obviously fell within the bounds of wise foresight. Thus, arrangements were made during the winter of 1915/16 for the experimental manufacture of 9·45-in. bombs, and bulk output was finally organised to patterns provisionally approved about February, 1916.[2] This action involved the building up on a large scale of acetylene and electric welding capacity, while its utilisation depended on the final decision between this type and others, notably the Sutton Armstrong heavy mortar, which was not finally rejected until 12 January, 1917.[3]

In fact the vital need for keeping pace with the mushroom growth of an entirely novel demand drove supply authorities responsible for trench warfare stores to disregard the normal procedure intended to ensure safety and efficiency, important factors in the effectiveness and morale of the army. The first urgency passed away with the building up of stocks towards the end of 1916; but the problem of effecting a nice balance between development of pattern and speed in production remained the outstanding feature in the supply of trench warfare stores until their standardisation was practically completed in the spring of 1918.

IV. Relations with the Trade.

(*a*) Close Control over Production.

The practice developed by the Trench Warfare Supply department of obtaining all stores from numerous small commercial firms necessitated very close central control over the various stages in experimental production. This was mainly effected by means of outside engineers. Their number and functions increased rapidly from the first appointment of a few "inspectors" in June, 1915. They examined the quality of certain stores, found new sources of supply, hastened production and acted generally as technical advisers to contractors. They worked throughout the country within definite areas reporting to the headquarters of the Outside Engineering branch at the offices of the Trench Warfare Supply department. The branch thus acted as a general intelligence department, keeping supply officers informed of the actual conditions of manufacture and providing a means of speedy intercommunication upon difficulties arising out of experimental production.[4]

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[1] (Printed) *Weekly Report* No. 19, III. (4/12/15).

[2] T.W. Contract, 2019.

[3] D.G.M.D./G./269; T.W. 2769/228.

[4] Hist. Rec./H/1600/11.

The lines of this organisation cut across the general system of the Ministry for utilising local knowledge and effort. During the last three months of 1915 various attempts were made to provide some administrative method whereby due use might be made of the local area organisation existing for the production of standardised munitions, without sacrificing that direct control over contractors which trench warfare supply officers regarded as essential to speed in the output of experimental stores. A provisional arrangement, drawn up on 5 October, 1915, established trench warfare engineers in nine local areas where they were to act in close conjunction with area engineers.[1] At the same time it was stipulated that trench warfare orders should be placed through Boards of Management except in the case of firms who were already contracting directly. The large number of direct orders then in existence practically nullified the intention of this agreement.[2] Accordingly, after considerable discussion between the departments concerned, a settlement[3] was reached on 17 December, 1915, whereby trench warfare supply officers undertook to place 80 per cent. of their future orders through Boards of Management, retaining the actual administration of such orders and keeping in close touch with the technical details of manufacture by means of the trench warfare outside engineers. In point of fact there were numerous deviations from the 80 per cent. rule during the succeeding year, both by special arrangement with individual boards and by the practice of certain officers who estimated the output of firms contracting indirectly as a mere margin of capacity.[4] The impracticability of adhering to the rule in producing purely experimental stores or those needing special technical knowledge was admitted in January, 1917. Nearly all trench warfare stores were then regarded as falling within one or other of these categories. At the time, production of the more standardised articles, such as the Mills grenade and the 2-in. trench mortar bomb, was being reduced because of the existence of stocks and in view of the proposed substitution of the 6-in. for the 2-in mortar.[5] In consequence, the question of renewing orders for these did not arise.

In the meantime the functions of the outside engineers had considerably expanded, although their duties in regard to inspection had practically ceased. Arrangements had been made to ensure that they should deal with all trench warfare supplies. From July, 1916, onwards their duty of reporting on capacity was extended to include systematic investigations in conjunction with the Area Organisation department and the Machine Tool department,[6] and upon the establishment of area clearing house-boards, trench warfare engineers

[1] T.W. Office Minute, No. 9.

[2] C.R. 2931 ; T.W. 1689 ; Unregd. Memo. T.W. Grenade Section F. 441.

[3] T.W. 1689.

[4] D.A.O./Misc./178 ; Hist. Rec./H/1610/16, p. 10.

[5] D.A.O./Misc./460.

[6] T.W. Office Minute No. 107.

formed one of the three executive officers on each board. In October, 1916, the outside engineer's certificate of capacity became an essential part of the procedure in placing trench warfare contracts.[1] In May, 1917, co-ordination with the area authorities was strengthened by a rule that the local board's opinion as to capacity should be notified on the outside engineer's certificate. The Outside Engineering branch had become responsible for all questions relating to priority of labour, machinery or materials in the previous December.[2] Finally, in the spring of 1918 the outside staff of the branch was absorbed in the newly-formed Central Engineering department[3] at a time when the practical standardisation of trench warfare stores had eliminated the conditions upon which its separate entity had been grounded.

(*b*) Co-operative Manufacture.

The limited facilities available in the comparatively small works to which orders were confined by the Trench Warfare Supply department gave rise to various experiments in co-operative or group manufacture. Thus two Birmingham grenade contractors gave mutual help in July, 1915, the one loading empty grenades made by the other, the second making component parts for the first.[4] Production of a thousand 3-in. Stokes mortar mountings was organised on the group principle in February, 1916. Drawings were divided into sections according to the class of work entailed. Contractors, notably motor-car manufacturers already engaged in making the mortars, undertook to supply the whole thousand of each section so that inspection and gauging might be facilitated. The department provided the special gauges needed, the contractors, standard gauges. In order to facilitate manufacture all small details, such as bolts, were made to standard commercial sizes.[5] Similarly, the manufacture of the 9·45-in. trench mortar was distributed among certain Glasgow firms, which severally undertook the various processes of forging, machining and assembling and the manufacture of the carriages.[6] Co-ordination of the various stages of production was the duty of the outside engineers, who were considered essential to this purpose. The methods thus worked out were successfully applied in systematic detail to the supply of mine sinkers for the Admiralty when that department had exhausted all the ordinary capacity of the country for this purpose.[7]

(*c*) Sub-Contracting.

During the first stages in organising trench warfare production by the trade, the subdivision of manufacture among numerous small firms

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[1] T.W. Office Minute No. 111.

[2] *Ibid.*, 126.

[3] General Memorandum No. 67.

[4] T.W. 376.

[5] D.A.O./Misc./168.

[6] Mr. Roger to Dr. Addison, 3/12/15 (C.R./T.W D./1121).

[7] Appendix III.

led to considerable difficulty in checking sub-contracting when the firms chosen were restricted as to plant and labour. The normal form of trench warfare contract retained the clause prohibiting sub-contracting without permission; but it was the general practice at first to allow firms to put out a much larger proportion of the work than was usual in the case of standardised munitions.[1] A considerable amount of sub-contracting had originated from orders placed before the formation of the Ministry. Thus one firm of grenade makers had given out work on grenade bodies and had subsidised one sub-contractor.[2]

The elimination of unsatisfactory sub-contracting was a gradual process[3] chiefly effected by a continuous endeavour to rule out all agents or middle-men.[4] Even in July, 1915, when knowledge of grenade manufacture was rare and the position of supply extremely urgent, decision was taken on principle against accepting the offer of an experienced firm to take responsibility for all grenade orders within a certain district.[5] When sub-contracting did obtain, it was a general practice among trench warfare engineers to eliminate intermediaries between contractors and their sub-contractors for all articles except small standard stores.[6]

(*d*) Effects of Novelty and Urgency on Prices.

The normal cost of trench warfare munitions was considerably less than that of ordnance generally since the means and methods of manufacture were comparatively simple, the class of labour needed almost entirely unskilled, and the materials used relatively common. Indeed, during the last quarter of 1917, when the experimental stage was practically completed, the total cost of trench warfare supplies was calculated as 9 per cent. only of the charges for all stores within the ordnance group.[7] In the initial period, however, and particularly during the year 1915, the entire novelty of the manufacture, and constant changes in the design and the numbers required, gave rise to very high prices. Thus one firm charged £11 11s. 4d. per thousand for loading Mills grenades at a time when no experience in this work could be adduced to check the cost, and was afterwards able to continue the same work at £4 per thousand. The supply department was at a disadvantage in negotiating terms with inexperienced manufacturers, who were unwilling to venture upon the risks of a novel enterprise without covering themselves fully. Thus the smaller fireworks firms, whose capacity was essential to the scheme for producing emergency

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[1] Mr. Roger to Lieut. Sutton, 18/8/15 (T.W. 2390); C.R. 2931.

[2] 75/3/2485.

[3] Conference with D.A.O., 22/11/15 (Unregd. Memo. Grenade Section F. 441).

[4] Mr. Roger to Dr. Addison, 30/11/15, 30/12/15 (C.R./T.W.D./1121).

[5] T.W. 538.

[6] D.D.G. T.W.S. Circular, 9/2/17.

[7] M.C. 646.

grenades, demanded excessive prices for filling the Ball type in July, 1915. In such cases a policy of deliberate delay in fixing terms until experience should have been gained resulted in considerable reductions. The price eventually settled for loading Ball grenades was £3 15s. per thousand as against the £12 10s. originally asked. At the same time much persuasion was needed to induce the contractors to continue operations pending the settlement of terms.

Again experimental orders were necessarily placed for small numbers and under extraordinary conditions of urgency. For instance, trial orders for 50-240 mm. bombs were placed with six different firms on 29 December, 1915.[1] These were executed on a cost plus percentage basis, which was reduced after experience to a basic price of 62s. 6d. per bomb[2] exclusive of the Ministry's contributions to capital expenditure. In the meantime one contractor supplied through the Director of Munitions, Scotland, various small quantities manufactured by diverse methods, charging prices which ranged from £4 10s. 6d. to £7 0s. 9d., in view of the smallness of the quantities and the extra cost of overtime on a "rush" order.

Special terms were arranged with individual firms to meet constant modifications in pattern. A noteworthy instance of the effect of fluctuation in design was that of the 3-in. Stokes bomb. Considerable inconvenience was caused to contractors by a triple change in the pattern of the cartridge container between April and June, 1916. Compensation was allowed to certain of the contractors in view of their commitments for material and expenditure on plant.[3] In placing contracts for purely experimental stores, such as those for the 240 mm. trench mortar bombs, it was agreed that prices based on manufacture to provisional specifications should be subject to variation either way to meet subsequent changes in design or in manufacturing methods.[4]

During the early months of urgent demand supply officers conducted all negotiations, the final contract being submitted by the Trench Warfare Contracts section to the Director of Munitions Contracts for signature, under a ruling of 13 July, 1915. Orders were then often given informally by letter in order to obtain the benefit of postponing the settlement of terms until manufacturing experience had been acquired. From 14 January, 1916 onwards, the advisers on contracts and finance attached to the supply department were present at conferences, and were kept informed of negotiations from the beginning. The close co-ordination thus secured in dealing with the comparatively limited numbers of contractors for trench warfare stores resulted in considerable economies.[5] During this year a considerable all-round reduction in prices effected a saving of nearly £160,000 weekly.

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[1] T.W. Contract 2019.
[2] *Ibid.*, 3057.
[3] *Ibid.*, 894.
[4] *Ibid.*, 3057.
[5] HIST. REC./R/263. 6/7; cf. Vol. III., Part I., p. 43.

The earlier payment of high prices was grounded on the need of the time for obtaining early deliveries at any cost. Occasionally this object was nevertheless defeated by the inefficiency of the firms chosen. In respect to these facts, it was alleged that "the urgency of requirements presented a serious obstacle to protracted negotiations on the subject of price, and in some cases it was literally impossible in the time available for the department to satisfy themselves that contractors were efficiently equipped to give delivery in the time stipulated." A successful experiment was carried out in the case of the Boase and Newton fuses, ordered in February, 1916, in order to complete a large stock of filled bombs then held up for lack of the service fuse. In this instance a bonus was given for prompt delivery,[1] and the fuses began to come forward early in March.[2]

(e) General Results of Fluctuation in Demand.

There was, further, a tendency among contractors to guard against fluctuations in trench warfare orders by means of an inflated price. Thus, the main reason adduced by one contractor in January, 1917, for claiming a 15 per cent. profit on detonators produced for trench warfare purposes as against 12½ per cent. on gaine detonators for shell was that orders for the former were most irregular, and from the very nature of things were likely to remain so, whereas the latter were required in absolutely regular weekly quantities.[3] The sudden reduction of requirements to which tactical developments from time to time subjected these stores was met at an early date by reducing the normal contract period to one of thirteen weeks, and subsequently by adopting the War Break Clause in common with the rest of the Ministry.[4] Cancellation of contracts due to reduction in a demand rarely gave rise to cases for compensation[5]; when this did take place, considerable saving was effected by the method adopted by the department's outside engineers in pricing uncompleted articles in an ascending rather than a descending scale.[6]

The change from emergency types to more efficient stores occasionally left the department with large surpluses of the less satisfactory weapons. There was a tendency on such occasions to press the Army Council to reconsider its decision. Obsolete stores, such as the West spring gun, were sometimes accepted for training purposes. Occasionally the War Office recommended that the surplus store, as, for instance, the Leach catapult, in March, 1916, should be scrapped.[7] Some types of obsolete grenades were reduced to their

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1 T.W. 4189.

2 (Printed) *Weekly Report* No. 33, III. (11/3/16).

3 T.W. 2050.

4 Hist. Rec./R/263. 6/7.

5 *Ibid.*

6 Outside Engineering Branch, Third Conference (4/6/16).

7 D.M.R.S. 262.

component parts.[1] In December, 1916, storage and the spreading of commitments over extended periods accounted for large numbers of the Mills grenades which had been ordered to meet over-estimated requirements.[2] Many surplus stores were offered to Allied Governments—*e.g.*, large quantities of Ball and Lemon emergency grenades were sent to Russia in 1916.[3] Certain of the more efficient mortars, withdrawn from use in the field when the number of types was reduced in 1916, were afterwards utilised for arming merchant vessels.[4] The department's system of direct issues overseas added a practical difficulty in congestion at works upon the sudden reduction of a demand, until the stores were established at ports of issue, viz., Newhaven and Bristol, in December, 1915. From this date onwards the storage capacity for trench warfare purposes increased rapidly; but these measures only alleviated in part the grave results of fluctuation in demand. Not only was financial loss hazarded either by the Government or by the firm concerned, but it was with difficulty that output was rebuilt to meet any subsequent increase in the requirement.[5]

V. National Filling Factories.[6]

The policy which confined the production of trench warfare stores to the trade was extended to every operation in their manufacture with the exception of the filling and assembling of trench mortar ammunition, and later a certain small amount of rectification which involved the handling of explosives. The comparatively simple process of loading grenades was at first restricted to contractors' works. The original intention was to place contracts also for filling the greater part of the trench mortar bombs.

(*a*) Initiation of Four Bomb-filling Factories.

When the Ministry came into existence the capacity of the Royal Laboratory was only sufficient to fill bombs of its own manufacture. Messrs. Vickers contracted for filled bombs for their own trench mortar; the loading of half the 3·7 in. bombs then under manufacture had been undertaken in the preceding January by Messrs. Roburite and Ammonal, who were making the explosive with which to fill them. No other trench mortar bomb-filling capacity was in existence. The vast

[1] Hist. Rec./H/1640/1, p. 20.

[2] D.G. T.W.S. to Dr. Addison 15/12/16 (C.R./T.W.D./1121).

[3] D.M.R.S. 262A.

[4] D.G. T.W.S.D. to Dr. Addison, 6/3/17 (C.R./T.W.D./1121).

[5] Mr. Roger to Dr. Addison, 2/5/16, 6/6/16 (C.R./T.W.D./1121).

[6] Based, where no other reference is given, on the weekly reports of Director T.W. 10 (Filling Stations and Stores). This account relates to those factories which handled trench warfare supplies proper. Several others controlled by the Trench Warfare Supply Department handled miscellaneous stores such as chemicals and mine-sinkers. Reference is only made to these where it is essential to the comprehension of the narrative.

expansion of the manufacturing programme for trench mortar ammunition in July and August, 1915, necessitated corresponding arrangements for filling the trade-made bombs. It was estimated on 24 August, 1915, that four or five factories would be needed for this purpose.[1] Arrangements were made immediately to erect three factories in the close neighbourhood of ammonal works, one at Erith,[2] in Kent, near the Thames Ammunition Works; one at Denaby,[3] co. Yorks., adjacent to the factory of the British Westfalite Company; and the third at Watford,[4] on part of a site taken by the Explosives Supply department for the erection of a new ammonal factory. The buildings for all three were erected at Government cost, but only one, the Watford factory, was originally intended as a national factory. The primary intention was that Erith and Denaby should be operated by the neighbouring explosive firms on terms which were left open. The new filling factories were located in the neighbourhood of ammonal works in order to avoid unnecessary transport of a hygroscopic explosive. A grave disadvantage lay in the increased danger risks to which both the explosive and the filling factories were thus exposed. This danger was increased when it was decided that bombs should be packed at the filling factories together with all components ready for issue. The handling of detonators involved an extra risk, which the British Westfalite Company would only accept upon the department's undertaking to indemnify them in case of explosion, fire, damage by enemy aircraft, and also for any contingent loss of profit from the neighbouring explosive works.[5] The land for the Erith and Watford factories was taken under the Defence of the Realm Act, the Watford site being transferred from the Explosives Supply department. The site for the Denaby factory was acquired on lease from the British Westfalite Company.

The factories at Erith and Watford were erected during the autumn of 1915 by local contractors on a cost plus percentage basis and under the immediate supervision of a director of construction, Mr. R. Adam, appointed by the department. The Thames Ammunition Company contracted for modifications needed to adapt certain buildings which already existed on the Erith site. The British Westfalite Company undertook to erect the Denaby filling factory, placing orders by competitive tender, subject to the department's approval, and charging no commission beyond a certain allowance included in a certain fixed sum received for all services rendered by the end of 1915. Little knowledge existed in the country of the lay-out necessary for a bomb-filling factory. The agents at Denaby guaranteed that the premises which they erected should be suitable for the purpose. The director of construction obtained a certain amount of information as to the lay-out for the other two factories from a visit to the somewhat primitive

[1] Mr. Roger to Dr. Addison, 24/8/15 (C.R./T.W.D./1121).

[2] Appendix VI.

[3] Appendix V.

[4] Appendix VIII.

[5] T.W. 5886.

bomb-filling shops which had been improvised at the Ordnance Factory under strenuous circumstances. An important departure was, however, made in the method of filling. At the Ordnance Factory melt-filling was the only method used. In the new Trench Warfare filling factories ammonal was stemmed by hand in powder form. The buildings were light and of a temporary nature, consisting of filling sheds, receipt, inspection and despatch stores, and magazines for the explosive. Very little equipment was needed, since the ammonal was to be received ready prepared and the actual charging was to be done by hand.

Structural work began at Denaby about the middle of August, 1915, the intention being to erect a factory to handle 70,000 3-in. Stokes bombs weekly. Verbal instructions were given to the Thames Ammunition Company to proceed with the conversion of the buildings existing at Erith on 21 August.[1] It was proposed that this factory should fill 20,000 2-in. bombs weekly. Watford was designed for the same number of 2-in. bombs, and was projected by 3 September, 1915. The main buildings at all three factories were completed by February, 1916. In the meantime filling operations had begun while structural work was being continued. Operations began at Erith on 9 October; Watford started a week later upon 3-in. Stokes bombs, turning over to the 2-in. in the following December, when Denaby began filling Stokes bombs. Another factory had been allocated to 3-in. Stokes bomb-filling towards the end of October. This was at Fulham,[2] where the W. E. Blake Explosives Loading Company had erected premises for loading ball grenades in August, 1915.[3] Experimental filling of Stokes 3-in. bombs was started in the grenade-filling shops during the third week in October.

The organisation of filling operations began in good earnest towards the end of November, 1915. A director of filling stations (Mr. F. B. Sanderson) was appointed on 19 November.[4] Regulations were drawn up to cover all four factories. Schedules of wages were considered, and the management of the Watford factory was set on a sound financial basis.

(b) NATIONALISATION OF THE BOMB-FILLING FACTORIES.

Until Mr. Sanderson undertook the control of these factories, it had been intended that Watford only should be managed from headquarters. It was originally proposed to transfer the buildings at Erith and Denaby to the neighbouring explosives firms when construction was completed. Similarly, the first intention was that the Stokes bomb-filling at Fulham should be undertaken under contract by the Blake Explosives Company. In September, 1915, Mr Adam had suggested that the Thames Ammunition Works and the British

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[1] T.W. Contract 1624.

[2] Appendix VII.

[3] T.W. 1109.

[4] Mr. Roger to Dr. Addison, 19/11/15 (C.R./T.W.D./1121).

Westfalite Company should respectively let the site of the filling factories at Erith and Denaby to the Government, taking the buildings at a nominal rent for the sole purpose of filling trench mortar bombs either at a fixed price or on a cost plus percentage basis. He proposed thus to avoid any capital charge upon the filling contract and at the same time to establish the State ownership of the buildings.[1] The new director considered that any agreement involving the renting of land from contractors or the letting of Government-built premises to them would enable them to make excessive profit. He accordingly proposed to substitute an agency agreement with the three firms. The scheme was accepted by the British Westfalite Company in a slightly modified form. They undertook to construct, equip and manage the Denaby factory in accordance with instructions from the department's technical representatives. The Minister bore the entire cost of construction and operation, providing all materials free of charge except the explosive, which was supplied by the agent at a fixed rate. The agents were responsible for labour, upkeep and repair, appointments of staff at £200 per annum or more being subject to approval. A fixed yearly fee was to cover establishment and administration charges. In addition, the agents were to receive a bonus on every thousand bombs filled and accepted to a minimum of £10,000 yearly.[2]

It was found impossible to reach a reasonable financial agreement along these lines with the contractors at Erith and Fulham. Moreover, in both cases adverse reports had been received as to safety precautions and the conditions of labour. After a systematic inspection of the Fulham Factory on 7 February, 1916, the Medical Inspector of Factories and the Chief Inspector of Explosives reported that the general conditions were unsatisfactory, and recommended reorganisation to secure a definite demarcation between "clean" and "dirty" areas, provision for the welfare of the workers, reduction in hours and re-arrangements to secure the cubic space required under the Factory Acts. In view of these circumstances, it was decided to nationalise both factories, and Erith was taken over as from 27 January, Fulham from 11 February, 1916. The buildings were rearranged; conditions were brought into line with Home Office regulations, and steps were taken to ensure the welfare of the workers by the organisation of canteens and by a systematic medical service.

(c) Erection of a Fifth National Factory and Expansion of the Work Undertaken.

The erection of a national factory for filling the heavy trench mortar bombs then about to come into supply began on a second site at Watford in February, 1916. This building, known as Watford No. 2,[3] was erected on land taken under the Defence of the Realm

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[1] Mr. Adam to Mr. Roger, 18/9/15.

[2] T.W. 5886.

[3] Appendix IX.

Act, and was practically completed by the following June. The filling of heavy trench mortar bombs took place at Watford No. 1 until August, 1916, when this work was finally transferred to the new factory. A single management controlled the two factories.

The establishment of trench warfare national filling factories ceased with Watford No. 2. Any further extensions in the programme of trench warfare work which required the handling of explosives was met by expanding the existing premises. The capacity of Denaby was considerably increased during the summer of 1917, and output at this factory rose to 110,000 3-in. bombs weekly in August, 1917. Throughout the war its work was restricted to the filling and assembling of 3-in. Stokes bombs, except for a few weeks in May and June, 1917, when the disassembling of 3·7-in. bombs was undertaken owing to a suspension in the output of Stokes bombs. Similarly, the work at the Erith factory was limited to the filling of medium trench mortar bombs, viz., the 2-in. for which it had been built, until May, 1917, when it began to fill 6-in. Newton bombs which were gradually to replace the 2-in. in the field. The change involved a total reorganisation of the factory, since the new type required double the amount of handling, labour, and storage needed for the old. In the spring of 1917 the capacity at Erith was increased from 20,000 to 25,000 bombs weekly; but difficulties of transport and labour prevented any further extensions. Both at Denaby and Erith general improvements in efficiency had brought the actual output considerably beyond the capacity for which the factories were originally planned before any additions were made.

While the work of the trench warfare national factories was thus confined at the outset to the filling of trench mortar ammunition, there followed a notable increase in the classes of work undertaken when once output in bulk had begun. This was due partly to the need for utilising spare capacity set free by constant changes in programme, partly to development in the functions of the Trench Warfare Supply department. In January, 1916, the department took over the supply of fuses for trench mortar bombs from the Gun Ammunition department. In the following month new and simple fuses were adopted, and the work of assembling these was allocated to the two Watford factories. During the summer of 1916 drastic reductions in the programme for trench mortar ammunition set free considerable capacity at Fulham and the two Watford factories. New classes of work were accordingly undertaken with a view to economy. The manufacture of fireworks was initiated at Fulham in June, 1916, to meet a very urgent demand. Work on aircraft bombs was undertaken at Watford No. 2, where arrangements had been made for loading considerably more 9·45-in. trench mortar bombs than were eventually required. The assembling of 336-lb. aerial bombs already charged with trinitrotoluol began at this factory in May, 1916; and the actual filling of 112-lb. bombs with amatol from the neighbouring explosive factory began in the following September. Thenceforward aerial bomb filling occupied an important

position in the general programme of this factory. The more dangerous operations in connection with assembling gas-filled and incendiary projectiles were concentrated at Watford No. 1, since it was the smaller of the two factories. Previous to June, 1916, a contractor at Walthamstow had charged grenades and shell with lachrymatory liquid and had also assembled the filled projectiles. The Walthamstow factory was then nationalised, and processes involving the handling of high explosive in close proximity with chemical mixtures were removed thence. Watford No. 1 undertook the assembling of 4-in. Stokes trench mortar bombs, including the hazardous operation of filling with ophorite a gaine fixed into the bomb. Medium trench mortar ammunition was also filled with thermit at this factory in July, 1916. Thenceforward the work of assembling chemical bombs tended to increase there, and upon one occasion during May and June, 1917, the whole capacity of the factory was devoted to this purpose. The fitting of gaines into Livens projector drums filled with poison gas was allocated to the second Watford factory in March, 1917. The construction of a national station for assembling chemical shell at Greenford began in August, 1916. While it was being built, the Walthamstow factory continued to assemble lachrymatory shell, the Ordnance Factory lethal shell. With the increase in the chemical shell programme it became necessary to double the capacity of Greenford. A contemporaneous reduction in the 9·45-in. trench mortar bomb programme set free considerable capacity at Watford No. 2, and in April, 1917, a scheme for assembling there 20,000 chemical shells weekly was preferred to the erection of a second station. Half the capacity of the factory was accordingly devoted to this class of work during the summer of 1917.

In October, 1916, it was ruled that contracts should not be placed until the capacity at the national factories had been fully utilised. These were to be regarded as particularly reliable contractors working at cost price and fulfilling the requirements of the Ministry as to factory conditions.[1] Accordingly, the original practice of confining grenade filling to the trade was partially reversed. Spare capacity at Fulham was used for loading hand grenades from November, 1916, onwards, and the filling of rifle grenades began at two national factories (Fulham and Watford No. 1) in the following March.

(*d*) Main Features in the Work of the Trench Warfare National Factories, 1915–17.

So far as bomb-filling was concerned, little change was made in the equipment or processes first used. The factories had been built very simply for hand-stemming ammonal into trench mortar bombs. The equipment of Watford No. 2, where heavy bombs were to be handled, was rather more complex. A change over from 2-in. bombs to 6-in. at Erith involved certain alterations to facilitate the handling of the heavier type. Hand-stemming was preferred generally

[1] T.W. Office Minute No. 110, 3/10/16.

to filling by machinery in view of the unsettled design and type of the bombs.[1] Small time and labour saving apparatus was, however, introduced gradually. A notable instance was the use of pneumatic apparatus for filling Mills grenades at Fulham.

The substitution of 80/20 amatol for ammonal as the bursting charge of trench mortar ammunition was accomplished gradually between January and May, 1917, without involving any drastic change in factory practice. This result was gained by retaining cold-filling in preference to hot-filling, which had been recommended in view of the superior crater-effects obtained. The change to hot-filling would have entailed the entire reorganisation of the factories to allow for the mixing of the explosive on the spot. The practicability of rearranging the factories for this purpose was under discussion during the first four months of 1917, but the scheme was definitely abandoned on 19 May and the factories continued to receive the explosive ready mixed for cold-filling.

Capital expenditure on the factories increased with their development. In February, 1916, the total cost of the four national bomb-filling factories was estimated at £110,000, divided as follows :—

Denaby	£ 6,000
Erith	24,000
Watford (1)	15,000
Watford (2)	65,000

Shortly afterwards Fulham was added to their number, and by the end of the year 1917 the total capital expenditure on the five factories was estimated at £192,420, divided in the following proportions :—

Denaby	£13,066
Erith	35,042
Fulham	16,860
Watford (1)	40,587
Watford (2)	86,965[2]

It was maintained that the nationalisation of bomb-filling resulted in an increase of efficiency and a reduction in cost. Any detailed comparison of costs before and after the nationalisation of contractors' factories is impracticable, since operations had not begun on a large scale when these were taken over. Certain distinct benefits were obvious. The actual cost of filling 3-in. Stokes bombs at national factories was 8¾d. per box of three as against 3s. 6d., the contract price originally asked, or 1s. 9d. the price arrived at after negotiation. The actual cost of filling a single 2-in. bomb was 5¼d. as compared with 3s. 6d. claimed by the contractor. The immediate effect of reorganisation at Fulham after its transfer to the department was a reduction of the employees by 70 persons without any corresponding decrease in output, and later rearrangements effected a further reduction in the labour by 25 per cent. The high degree of efficiency attained at the national factories served a double purpose. Not only did it result in

[1] Unregistered Memorandum, D.G. T.W.S. to D.T.W.10, 25/5/16.

[2] C.R. 2913.

large and satisfactory output, but it also enabled comparison of costs among contractors employed upon such operations as firework making and grenade filling. In April, 1917, administrative changes were effected with a view to concentrating control over national factories and contractors engaged upon similar operations and thus obtaining to the full the advantages of such comparison. The Director of Trench Warfare Filling Stations then became responsible for the administration of all trench warfare contracts for operations involving the handling of explosives except only the production of components. His technical staff inspected contractors' works and gave advice as to the means of conforming with Home Office regulations, particularly the rules as to handling trinitrotoluol then recently promulgated. The system of book-keeping and store-accounting which had been instituted at the national factories was extended to contractors. The centralisation of control over operations involving the use of explosives was practically completed about January, 1918, when the Director of Trench Warfare Filling Stations became responsible for all explosive-filled components except only grenade-detonators.

A considerable amount of experimental work was carried on at the national factories. Constant changes in design seriously affected the output of the factories and gave rise to difficulty with the employees, who occasionally became discontented on account of constant variations in the details of their work. When conditions fluctuated so frequently it was difficult to retain labour. Short time could rarely be worked in localities such as Erith and Watford, where competition for labour was high. In addition to the allocation of new work to the factories, stock work on obsolete stores was spread among them in order to retain the workers.

(*e*) Salvage and Rectification.

The breaking down of obsolete stores and the rectification of those rejected became a matter of importance during the year 1917 by reason of the general shortage of material. Breaking down, therefore, began at Trench Warfare stores in addition to the filling factories and was extended to nine of the department's stores. In one instance a store (Daneshill) was converted to this use only. It was laid down as a general principle that the breaking down or rectification of trench warfare weapons should be undertaken at the national stores when purely mechanical operations were concerned, but that all rectification which involved explosive risks or the use of power-driven machinery should generally be restricted to national factories. For this reason plant for rectifying trench mortars was installed at the Buxton store in July, 1917. A scheme initiated in November, 1917, for concentrating trench warfare salvage operations at Chipping Sodbury, near Bristol, was short-lived, since the site chosen was found to be in dangerous proximity to the Great Western main line. Occasionally breaking down was undertaken by contractors. For instance, the Perivale Explosives Company undertook in May, 1917, to empty 300,000 obsolete grenades returned from overseas. The repair of boxes for

bombs and grenades was carried out at a national factory established at Beddington in November, 1916.[1]

VI. Standardised Production, May-November, 1918.

One of the chief reasons given in May, 1918, for combining the control over production of trench warfare stores with that of guns and gun ammunition was to ensure economy by the pooling of capacity. This was only practicable in those operations where the difference in the nature of the stores had least effect, *e.g.*, in the filling of trench mortar ammunition and in the practical handling of supplies, their transport and their storage.

The mechanical production of trench mortars, empty bombs and grenades presented few features of novel interest during the short period of warfare which followed the new arrangements of May, 1918. Nor was there any further important departure from the former practice of placing contracts for this work with numerous foundries and other comparatively small works without encroaching upon the capacity for gun and shell production. Most notable among the new orders for this class of work were those placed with various Scottish firms for the wire-winding of Livens projectors, a method intended to economise steel. Numerous orders for 6-in. bombs were placed with the iron founders of Edinburgh through the local Board of Management.[2]

On the other hand, the combination of administrative responsibility for filling and assembling trench mortar ammunition with that for filling and assembling shell facilitated a considerable allocation of trench warfare work to gun ammunition filling factories. Some such measure had been suggested in the spring of 1917, when the reduced shell programme had freed capacity administered by the Controller of Gun Ammunition Filling department and a change to hot-filling for trench mortar ammunition was under discussion. It had then been proposed that spare capacity for hot-filling at the Hayes National Filling Factory should be used for trench mortar ammunition; but the project was abandoned, since it would either have involved a dual control over the factory or a departure from the fixed policy of the Trench Warfare Supply department to keep direct supervision over every process in the production of its stores.[3] Shortly after the transfer of responsibility in 1918, some experimental filling of trench warfare stores was carried out at Hayes, while the Perivale Filling Factory, formerly entirely occupied with filling and assembling shell components, turned over in part to trench mortar bomb fuses such as the Allways fuse.

The actual filling of trench mortar ammunition and grenades was at this time occupying a diminishing proportion of the work carried out at the Trench Warfare national filling factories. Their work in

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[1] Appendix IV.

[2] *Firms and Factories List*, X35, *passim*.

[3] T.W.C. Minute (M) 244.

filling and assembling aerial bombs and assembling chemical shell was gradually increasing. The account of arrangements made for dealing with chemical shells at gun ammunition filling factories is considered elsewhere. Aerial bomb filling was continued at Watford (Trench Warfare) Factory No. 2 until the maximum capacity of the factory was reached. The surplus work of an increasing programme was then distributed among gun ammunition filling factories. Hereford undertook all 50-pdr. aerial bombs, Chilwell the hot-filling of the big S. N. aircraft bombs with 70/30 amatol. Towards the end of June, the utilisation of shell-filling plant at Georgetown for trench mortar ammunition filling was also under discussion. These arrangements were, however, entirely changed on account of the destruction of the press-houses at Chilwell on 1 July, 1918, and the consequent re-allocation of shell filling among other factories. The Trench Warfare national factories then contrived to meet the whole programme for filling trench mortar ammunition and to resume the 50-pdr. aerial bomb filling. This was effected by extending the hours of work, by continuing operations over the week-end, and occasionally by means of night-shifts. Chilwell continued the filling of heavy aerial bombs in the melt-houses which were undamaged, and shortly before the Armistice arrangements were again made for filling 6-in. trench mortar ammunition at the national shell-filling factories.[1]

Upon the disintegration of the Trench Warfare Supply department in May, 1918, the stores which had formerly been controlled by the director of trench warfare filling factories were transferred to different authorities according to their nature. Thus the stores for empty components were handed over to the Central Stores department, while those for filled bombs and grenades were taken over by the Army Ordnance department.[2] Accordingly, it became possible to benefit by the use of spare capacity at central stores for accommodating large numbers of empty components for trench warfare supplies which were produced during the summer of 1918 at a rate considerably exceeding that at which they could be used.[3] The transfer of magazines to the Army Ordnance department cancelled the Ministry's responsibility for the issue of trench warfare supplies which had been initiated in view of their experimental nature in 1915.

A large proportion of the productive capacity for trench warfare munitions was occupied during the last year of the war upon the manufacture of mortars and their ammunition for the equipment of allied armies, particularly the American Expeditionary Force. Some novel stores were developed. The Army in France asked for the supply of 500,000 anti-tank grenades on 28 April, 1918. When the War Office notified the Ministry of Munitions of this demand on 8 May the design was still incomplete. Experimental orders for fifty sample grenades were placed at once. The original project that a certain quantity

[1] (Printed) *Weekly Report*, No. 163, VI. A (12/10/18).

[2] M.C. 670.

[3] (Printed) *Weekly Report*, No. 149, VI. A. (6/7/18).

should meantime be made at General Headquarters, France, was abandoned in view of other urgent work arising out of the German offensive. Manufacture was, however, facilitated by the use of the percussion mechanism of another type (No. 24) returned from overseas for disassembling.[1] Manufacture and filling in bulk began in August, nearly 4,000 of this type of grenade being completed during the week ending 24 August.[2]

The six months during which production of trench warfare stores was controlled by the authorities responsible for ordnance supply formed too short a period to admit of any comparison between the results of normal methods and those of the special procedure adopted during the previous years of experimental manufacture. The few incidents narrated above served only to point a principle already recognised, viz., that economy in productive capacity might be obtained by centralising control over the production of standardised munitions, but that the speedy production of such trench warfare stores as were not yet of settled design still depended very largely on the use of a special procedure.

[1] D.M.R.S. 262 H.

[2] (Printed) *Weekly Report*, No. 156 (Statistics), Table III. (24/8/18).

CHAPTER III.

THE DEVELOPMENT AND SUPPLY OF TRENCH MORTARS AND THEIR AMMUNITION.

I. The First Three Hundred Mortars and their Ammunition, October, 1914—June, 1915.

(*a*) Development of the First Patterns.

The first demand for trench mortars was a direct result of the Battle of the Aisne. On 20 October, 1914, the Commander-in-Chief requested[1] the supply of some special form of artillery to be used with effect at close ranges in the trenches. He named as the chief *desiderata* mobility, great shell power, and accuracy at short range; and he urged that some armament of this nature should be provided immediately. Having dug themselves in as a means of avoiding high velocity rifle-fire at close quarters, the troops needed some form of high-angle fire at a short range to bombard the enemy's trenches and to cut his wire. This contingency had been foreseen by the German headquarter staff. Acting on the experience of the Russo-Japanese war, they had equipped their army with *minenwerfer* for use from infantry positions.[2] In Great Britain no experience had been obtained in manufacturing or using such weapons, nor did any pattern exist, a proposal made at the end of August, 1914, for copying German types having been set aside in view of more immediate demands on the capacity of the Ordnance Factory and armament firms.[3]

Upon the receipt of the Commander-in-Chief's demand, the armament firms were invited to prepare designs, and the Chief Superintendent of Ordnance Factories also took steps to develop a pattern. The first of these experimental weapons was produced by the Elswick Ordnance Company. It was a 5-in. B.L. howitzer, which was rifled. It fired 5-in. B.L. howitzer lyddite shells taken from the defence establishment and detonated with the No. 44 fuse. It was intended for firing from a retired position, and was sent to France on 3 December, but was condemned by the Commander-in-Chief as not meeting conditions which he laid down on 17 December, 1914. These were portability, compactness, invisibility, accuracy, and a range between 100 and 600 yd.[4]

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[1] 121/Stores/436.

[2] Hist. Rec./H/1600/14, p. 37.

[3] 121/Stores/436; 121/Stores/970; *Ordnance Board Minutes*, 11520 (ii).

[4] 121/Stores/970.

Meanwhile, Messrs. Vickers had converted a 75 mm. howitzer into a 3-in. mortar, which was not successful owing to the bulk of the weapon and the danger to friendly troops from the tail-piece or its bomb.[1] Trials of a second pattern were hastened in January, 1915. This was the "Vickers" 1·57-in. trench howitzer, firing a cast-iron bomb filled with permite, a perchlorate explosive, and detonated by a special fuse. The design was approved on 14 January, 1915, and six mortars with 250 bombs, weighing variously 18 lb. or 33 lb., were issued overseas on 8 March. This type of mortar was accepted by General Headquarters, France, on 21 March, and a request was made for twenty-five mortars, with fifty rounds of ammunition apiece, eighty per cent. of cast-iron bombs being allowed with a view to facilitating manufacture.[2] The number was subsequently increased, the total orders placed with the firm by the end of April being for one hundred and fifty mortars, with ammunition to correspond.[3] By the end of June, 1915, 127 of these weapons had been actually issued to France, with ammunition to correspond.[4] They were then generally approved as "good mortars and fairly effective"; but the one type of bomb was too light and the other only ranged about 200 yd.[5]

The efforts of the armament firms thus produced one acceptable type of mortar. Throughout the winter of 1914-15 the Chief Superintendent Ordnance Factories was attempting to improvise some kind of weapon to meet demands of continually increasing urgency received from all parts of the British front.[6] For the most part these requests were for the immediate issue of any kind of weapon to reply to the enemy's *minenwerfer*. Thus Sir Archibald Murray wrote on 4 November, 1914, that the exact size of the weapon did not matter provided it was accurate and portable and could fire a good charge of high explosive. Something practical to bring into action at the earliest possible date was needed rather than the ideal weapon produced by lengthy experiment. The Chief Superintendent of Ordnance Factories initiated trials for converting nine existing 7-pdr. guns into trench howitzers, by mounting them on small naval carriages and firing 12-pdr. B.L. lyddite shells fitted with a tube or stem, but had proved by 8 December that little chance of accuracy was to be gained by such a device.[7] A second experiment resulted in the development of a light 4-in. mortar, which was improvised by boring out a 6-in. shell. Orders for the manufacture of twelve of these "little trench howitzers," with 500 rounds of ammunition, were given by the Director of Artillery on 10 November, 1914.[8] All twelve had been issued with 545 rounds of

[1] *Ordnance Board Minutes*, 12029, 12313.

[2] 121/Stores/1554.

[3] *Order and Supply List*, No. A. 6, p. 29.

[4] Hist. Rec./H/1610/19.

[5] C.R./T.W.D./1120 (7).

[6] 121/Stores/529 ; *Ordnance Board Minutes*, 12008.

[7] *Ordnance Board Minutes*, 11736, 11880, 12059.

[8] 73/4/6488.

ammunition by the end of the year. Their arrival in France was greeted with elation, although they had defects which the army workshops remedied.[1] By the end of June a total of 40 of these mortars and about 3,000 rounds of ammunition had been issued.[2] By 24 July this mortar had reached its third mark, which had a rifle breech mechanism. It fired a steel bomb, which was studded to take the rifling, and weighed 8½ lb. It was fairly accurate and had a range of 900 yd.; but it was slow loading, and the shell case was expensive.[3]

(b) Local Manufacture.

The twelve 4-in. mortars were the only weapons of this kind issued for service use before the end of 1914. In the total absence of trench mortar supplies, the troops began to improvise their own and to establish numerous small workshops for this purpose. Thus, in December, 1914, the 4th Army Corps produced mortars by using iron water pipes to throw a "jam-pot" bomb, and experimented with old gun-metal mortars, the gift of the French Government.[4] Again, in the following spring, the 2nd Army established furnaces at Armentières, where brass 3·7-in. mortars were cast and machined. These were bartered with British troops in the line in exchange for the empty S.A.A. cartridge cases, out of which the weapons were made.[5] These methods of supplementing trench mortar stores by articles of local manufacture continued into the year 1916. Not only was the shortage of supplies thus ameliorated, but valuable results were obtained from the experiments carried out in the army workshops which were in direct touch with actual conditions in the field.[6]

One of the earliest mortars thus improvised was the 3·7-in. "pipe gun," a light mortar, of which eighteen had been made by sappers and miners of the Indian Corps under Lt.-Col. Twining, R.E., by the beginning of December, 1914.[7] Following information received from Colonel Twining, the Chief Superintendent of Ordnance Factories arranged to make at Woolwich one hundred of these mortars with 50,000 rounds of ammunition. He sent the first twenty to France with 1,000 rounds of ammunition on 3 January, 1915.[8] The gun was a smooth tube. The bomb was a "tin-pot" filled with ammonal and weighing 4½ lb. The mortar was therefore occasionally called the 4-pdr. The bomb was detonated by means of a length of Bickford fuse, directly ignited by the explosion of the propellant, and was in

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[1] *Ordnance Board Minutes*, 12594.

[2] App. XI, XII. Actually only 20 4-in. mortars were in France; 8 were despatched just before 20 July; 2 others were finished about 24 July. (App. II.)

[3] C.R./T.W.D./1120 (1).

[4] Gen. Rawlinson to Gen. von Donop, 13/1/15 (121/Stores/970).

[5] Hist. Rec./H/1600/14.

[6] C.R./T.W.D./1120 (4).

[7] *Ordnance Board Minutes*, 12002 (i), 12003 (ii).

[8] 121/Stores/970.

consequence very dangerous. For instance, eight out of eleven of the first guns issued had burst within ten days of their arrival in France.[1] Steps were taken to improve the mortar by adopting a rifle breech mechanism and providing canvas covers to prevent bursts, which had been traced to the accumulation of moisture in the barrel.[2] The Ordnance Factory had made 120 mortars by the end of June, 1915. Twenty were sent to the Dardanelles and the rest to France, while arrangements were made for expanding the source of ammunition supply by placing a single contract for 100,000 filled bombs on 30 January, 1915.[3] The first deliveries from the contractor, which had not been subjected to inspection by C.I.W., were found unsatisfactory and returned for rectification in April,[4] and effective ammunition did not come forward from this source until the last week in May.[5]

(c) THE 2-IN. MEDIUM MORTAR.

In the meantime a much more satisfactory pattern had been evolved and manufactured by the Chief Superintendent of Ordnance Factories along the lines of the Krupp mortar, a full description of which had been published in a German technical magazine as far back as 1910. After experimenting with 5-in. and 6-in. shells fitted with tubes and fired from a 7-pdr. gun, the Chief Superintendent of Ordnance Factories fitted 50-lb. spherical cast-iron bombs with steel tails, and fired them successfully from a 2-in. tube attached to a mounting similar to that of the 4-in. mortar. Supplies of 2-in. tubing were immediately procured, and two experimental mortars were sent to France with fifty bombs on 11 March, 1915. The type was accepted by General Headquarters on 21 March, and eventually became the standard pattern of medium trench howitzer. In requesting the supply of 25 Vickers mortars on that date, Sir John French asked also for the same number of 2-in. mortars, with fifty rounds of ammunition apiece.[6] The twenty-five 2-in. mortars had been issued to France with their ammunition by the end of June, and various improvements had been made in the pattern. A smokeless firing charge had been introduced, but the report and flash on firing still betrayed the whereabouts of the mortar, and the tail-piece of the bomb, which almost always projected backwards, was a frequent cause of casualties to friendly troops. Certain defects had also to be remedied before it was thought that the design would be suitable for manufacture by the trade.[7]

(d) ORGANISATION OF SUPPLY, JANUARY TO JUNE, 1915.

Thus by the end of June, 1915, four patterns of trench mortars had been evolved and were in service use. Rather more than 300 had

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1 121/Stores/970.
2 121/Stores/1482.
3 Contracts B. 7457.
4 94/B/36.
5 Appendix XI., note 2.
6 131/Stores/1554.
7 C.R./T.W.D./1120 (1); HIST. REC./H/1600/14.

been made and issued. Production, both of mortars and ammunition, was small and slow. All except the 2-in. mortar either fired too little explosive or had too short a range. More mortars were urgently required, with any amount of ammunition. The development of the 2-in. mortar had provided a powerful medium weapon, generally approved in regard to efficiency, portability and safety, in spite of the danger from the stick or tail.[1]

The first demand in October, 1914, had been for a heavy mortar resembling the German weapon. Subsequent information showed that the German *minenwerfer* threw bombs varying in size between "an orange and a coal box."[2] On 8 December, 1914, Sir John French asked to be provided with two types, a light mortar similar to captured German weapons recently sent home and a heavy mortar which he considered of importance.[3] In view of verbal and personal reports which were received during the winter and varied considerably in character, the Army Council asked for a further definition of the conditions to be met. A reply from General Headquarters, dated 29 January, 1915, again urged the need for two distinct types, a heavy mortar and a light one, similar to the 3·7-in., but without its defects.

In view of the "extreme urgency of getting something over to the Continent," the Ordnance Board had been instructed on 31 December, 1914, to devote attention to the problem of developing a mortar in the shortest possible time. They acted in conjunction with officers who had returned from France with the latest information.[4] During the next six months they investigated various means of improving the four types which were already developed. Two of these threw a light bomb weighing less than 10 lb., two threw a medium bomb weighing from 18 lb. to 50 lb. This last was the weight of the 2-in. bomb and was considered by many as large as was convenient for handling in a trench.[5]

Obviously, the urgent demand for a non-existent store could be met most speedily as well as most economically by producing a weapon which was simple to make and thus avoiding encroachment on the specialised ordnance capacity of the country, already over-driven. On the other hand, the very simplicity of hastily improvised weapons often involved dangerous features. Reporting on light German mortars sent home by the Commander-in-Chief towards the end of 1914, the Chief Superintendent of Ordnance Factories pointed out that their simplicity lay in the bomb, which would detonate however it fell and could therefore be fired from a smooth bore at any elevation ; but he considered this form of ammunition unsafe.[6] A proposal to use more common sources of supply was made by Mr. Wilfrid Stokes in January, 1915,

[1] Gen. Ivor Philipps (30/6/15) ; C.R./T.W.D./1120 (7).

[2] Sir A. Murray, 4/11/14 (121/Stores/566 A).

[3] 121/Stores/970.

[4] *Ibid.*

[5] C.R./T.W.D./1120 (7).

[6] *Ordnance Board Minutes*, 12002 (i).

when he suggested projecting a cast-iron "shell" from a solid drawn steel tube,[1] and using as a means of propulsion a sporting cartridge inserted in the bomb itself, or (later) in a container attached to the base of the bomb. Thus on dropping the projectile down the tube of the mortar the percussion cap was fired by its impact with a striker fitted in the base of the barrel. This method of loading gave great rapidity of fire; but the bomb as originally proposed was detonated by means of Bickford fuse, and gave the same risk of prematures which had already been experienced with the 3·7-in. mortar.[2] The project was therefore rejected.[3] It was again brought forward with the same type of fuse in March, 1915; but the 1·57-in. and 2-in. medium mortars had by that time been adopted, and it was decided not to increase the number of types then in use by the addition of a new invention.[4]

About a month after this decision (30 May) the Master-General of Ordnance gave instructions for the supply of trench mortar ammunition in increased quantities, stating at the same time that it would be impossible to have too much.[5] The number of mortars to be produced was in fact limited by the available capacity for producing the ammunition. This depended chiefly on one component, the fuse, and on the extremely restricted filling capacity of the Ordnance Factory.[6] The problem of fuse-production was among the greatest difficulties in the supply of bombs until the spring of 1916. All three of the safe service types (the 1·57-in., 4-in and 2-in) were used with fuses, the production of which was difficult and encroached on capacity needed for artillery fuses. This was particularly the case with the complicated time fuse No. 80, which delayed output of 2-in. bombs and was urgently required for 18-pdr. shells.[7] The alternative use of a Bickford fuse igniter in the 3·7-in. mortar was extremely dangerous. A satisfactory simple fuse capable of manufacture by the trade was the combination of a central fire cartridge-head and Bickford fuse, devised by the officers of the Trench Warfare Supply department for use with the 3-in. Stokes bomb. This time fuse proved more trustworthy than any "Allways" fuse up to the end of 1917, and the effective work of the Stokes mortar was largely due to its development during the autumn of 1915. The supply of fuses actually restricted ammunition output until the spring of 1916, when the development of special trench mortar fuses of simpler construction freed this store from dependence upon surplus artillery capacity.[8]

During the period under consideration (October, 1914, to June, 1915) the Ordnance Factory and one armament firm (Vickers) were the only sources of supply for service trench mortars. It has been seen that their output was supplemented by the Army in the field.

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[1] HIST. REC./H/1611/1, p. 2.

[2] *Ibid.*, H/1610/4.

[3] *Ibid.*, H/1611/1, p. 3.

[4] *Ordnance Board Minutes*, 13686.

[5] HIST. REC./H/1600/7.

[6] 57/3/4775.

[7] C.R./T.W.D./1120 (7).

[8] See below, p. 54.

Manufacture of the 2-in. mortar was restricted to the Ordnance Factory as a matter of definite policy, since the Chief Superintendent considered that direct control should be maintained until defects in the design were overcome.[1] The bombs manufactured for the 3·7-in. mortar by a single contractor were beginning to come forward towards the end of May, 1915. Outside assistance in making cast-iron bombs for the 2-in. howitzers had been obtained from the Brethren of Trinity House, who had offered to place their spare workshops at Blackwall at the disposal of the Arsenal in consequence of Lord Kitchener's statement as to the deficiency of war material on 15 March, 1915,[2] and undertook on 19 May to make 3,000 bombs at the rate of 300 weekly. Such sub-contracting added to the work of inspection at the Ordnance Factory, and the agreement was subsequently converted into a direct contract. The Chief Superintendent of Ordnance Factories attempted to bring in a few fresh contractors for the ammunition, to provide for the increased production of trench mortar ammunition which was ordered on 30 May, 1915.[3] These efforts had scarcely borne fruit when the newly-formed Ministry of Munitions undertook to supply all weapons for trench warfare in vastly increased quantities.

II. Production by the Thousand.

The design and production of the four approved types of mortars described above was controlled from the Directorate of Artillery. On 24 June, 1915, it was agreed between Lord Kitchener and Dr. Addison that the supply duties of the directorate towards these stores should be transferred to the Trench Warfare Supply department,[4] but the department did not actually take entire responsibility for trench mortars until the first week in July.[5] Information as to the numbers of mortars required had already been sent to the Director General of Munitions Supply, as shown in the table[6] below :—

STATEMENT OF TRENCH MORTARS AND AMMUNITION REQUIRED (8/6/15).

Nature.	*No. of Guns likely to be in the Field.*	*Nature of Ammunition Required.* *Shell.*	*Fuse.*
2 in. Trench Howr.	100 (10*)	H.E.	Fuse to be notified hereafter.†
1·57 in. „ „	300 (10*)	H.E.	Vickers fuse (special).†
4 in. „ „	30 (10*)	H.E.	No. 44 fuse.
3·7 in. „ „	150 (10*)	H.E.	Safety fuse and detonator.

* Number of rounds per day added in a subsequent minute (16 June).
† Ammunition for these natures urgently required.

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1 C.R./T.W.D./1120 (1).
2 70/Gen. No./4228.
3 57/3/4775 ; HIST. REC./R/1610/6.
4 Dr. Addison to Sir Reginald Brade, 22/7/15.
5 Dr. Addison to General Jackson, 7/7/15 (T.W. 2767).
6 Extract from 94/Gen. Nos./122 in D.M.R.S. 262.

The War Office had informed the Ministry on 24 June, 1915, that the number of trench howitzers likely to be in the field had been limited by difficulty in obtaining the necessary amount of ammunition. If the Minister saw his way to producing more than the daily ration asked for, the number of mortars should be increased accordingly.[1] The Military Secretary informed[2] the Secretary concerned (Dr. Addison) on 30 June that all four types were reported as more or less efficient and satisfactory; but all except the 2-in. used ammunition with too little high explosive or at too short a range. More mortars and any amount of ammunition were required. Three batteries of four mortars each with each division would be liked. This would mean 600 mortars with 50 divisions or 1,200 with 100 divisions. There was also an urgent though informal demand for mortars for the Dardanelles. Lieutenant F. A. Sutton, who had been in charge of Egyptian trench mortars in Gallipoli, had recently been invalided home, and was endeavouring to hasten the issue of efficient trench mortars to the Eastern front, to which 20 3·7-in. mortars only had been sent from home by 25 July, 1915. He took charge of the production of mortars and their ammunition until the beginning of September.[3] The table shown in Appendix II. was drawn up on 25 July, and represents the position as he ascertained it upon taking control, the remarks representing the opinions gathered by him during a visit to France. The action of the Trench Warfare department seems to have been based rather on the information thus obtained and that provided by the Military Secretary than upon the previous table, which had been forwarded to the Ministry about a month before responsibility for trench mortar supply had been formally transferred. The first efforts of the department were concentrated upon the rapid production of mortars and their ammunition, pending the slower process of organising the supply of guns and shell. The supply officers accordingly acted upon the presumption that it was of paramount importance to adopt types capable of speedy manufacture without encroaching on normal sources of armament supply.[4]

(*a*) INTRODUCTION OF THE 3-IN. STOKES MORTAR.[5]

The first step taken by the Trench Warfare department was to introduce the Stokes mortar as a weapon easily made by firms outside the ordinary makers of armament. Except for the production of steel tube for the gun barrel, the manufacture of this mortar was within the capacity of any small engineering firm possessing suitable lathes, small drilling machines and brazing hearths, and employing mechanics of average ability. On 30 June, 1915, Mr. Lloyd George with Major General Ivor Philipps (Military Secretary)

[1] D.M.R.S. 262.

[2] C.R./T.W.D./1120 (7).

[3] HIST. REC./R/1610/8.

[4] *Ibid.*

[5] For the documentation of this account, see HIST. REC./H/1611/1.

witnessed a demonstration of the mortar at Wormwood Scrubbs. On the same day General Philipps informed the secretary concerned (Dr. Addison) that one-thousand Stokes mortars should be ordered, together with 100,000 bombs, but that contracts for the latter should await the development of a satisfactory fuse. At the urgent instance of Dr. Addison the design authorities at the War Office submitted the mortar to the Ordnance Board for reconsideration on 3 July.

In the meantime the Trench Warfare department put in hand certain drawings, and on 26 July they placed provisional orders for the specialised production of the steel tubes required, arranging with a single firm of tube-makers to undertake the supply of 400 3-in. barrels and 100 4-in. barrels, although actual manufacture did not begin at once. Official trials of an experimental 3-in. mortar which had been made by Mr. Stokes were held during the second week in August. In the meantime certain provisional orders were placed for gun mountings and shells and for 20 complete 4-in. guns. The 4-in. mortar was invariably used with special ammunition. Its history is considered later.[1] The 3-in. Stokes mortar was tried at Shoeburyness in August, 1915, with high explosive bombs rendered less dangerous by the use of an igniting apparatus similar to that of the Mills grenade. Thereupon the Ordnance Board reported that this type of mortar was now safer than the 3·7-in. Formal approval of the mortar as then tried was notified on 28 August, on the understanding that the means of ignition was safe, the reliability of the Mills grenade having been called into question in the meantime. During the autumn the design of the ammunition remained under consideration and no formal approval of its use for service was given before the end of the year.

In the meantime Mr. Lloyd George had given instructions on 12 August that orders should be immediately placed for 1,000 Stokes mortars with two or three hundred rounds of ammunition weekly, relying on special funds to cover the expense in the event of the weapon's ultimate failure. The first explicit request for Stokes mortars was made some ten days later. On 22 August, General Headquarters, France, telegraphed to the War Office for as many Stokes guns and smoke shells for them as could be made available by 1 September, at the same time sending an officer to the Trench Warfare department to explain the purposes for which the mortars were needed. These weapons, which were hastily made and issued for providing a smoke screen at the Battle of Loos, were of 4-in. type, of which an account is given below. At the same time, the demand as it passed from the War Office to the Ministry made mention generally of Stokes guns and their ammunition, without allusion to calibre or the special character of the bomb. A more definite demand from the War Office for 200 3-in. guns with a trial lot of 100,000 bombs was received by the Ministry on 21 September.[2]

Provisional drawings of the 3-in. mortar were issued to hasten manufacture on 23 September, 1915. Gauges for the barrels were

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[1] See below, p. 92. [2] D.M.R.S. 98.

obtained at about the same date, their number being reduced as far as possible, although this arrangement hindered interchange of parts. Inquiry having shown that hot-drawn barrels could not be expeditiously obtained from the limited existing sources, entire reliance was placed upon cold-drawn steel. It was at first arranged that proof should take place at the Wembley Experimental Ground; eventually all the 3-in. mortars were proved at Shoeburyness, until the trench mortar proof range was established at Buxton. Orders were placed directly with general engineering firms such as motor makers and through the Boards of Management. A certain number of completed mortars was ordered from Ransomes & Rapier, the firm of which Mr. Stokes was managing director; but his schemes to organise manufacture along lines similar to the area organisation for shell production and to become personally responsible for the quality of output were rejected as impracticable.

By 1 November, 1915, the Trench Warfare department was aiming at the production of 800 3-in. mortars. The remaining 200 out of the thousand sanctioned by Mr. Lloyd George were to be of the 4-in. type. The earlier efforts of the department had been concentrated upon the immediate issue of as many 4-in. mortars as could be produced for the smoke screen needed in the September offensive. From November onwards the output of 3-in. mortars and high explosive ammunition was treated as the most urgent. The requirements for all trench mortars was stated more definitely by the War Office on 11 November, and showed a total demand for 1,280 3-in. guns, *i.e.*, 480 in addition to the 800 already on order.

Over 300 of these mortars had been produced by the end of the year; the whole 800 ordered in the first instance were delivered by 12 January, 1916, although 30 were still awaiting proof. Issues overseas had not yet taken place, but 200 mortars had been issued in England for instructional purposes. The output of ammunition was still too small to be effective in the field or to justify the immediate disclosure of a novel weapon. The mounting had proved weak and was being modified. The design of the bomb was still unsettled. A simple and efficient time fuse had, however, been contrived by combining a central-fire cartridge head with Bickford fuse. Upon taking responsibility for the design of munitions in December, 1915, General Du Cane insisted upon trials of 1,000 rounds before giving final approval to the mortar and its ammunition. On the whole these proved satisfactory, and provisional approval for the issue of the ammunition already manufactured was given in the first week of January, 1916. Manufacture had been continued pending these trials, and the issue of complete rounds began in the same week. The 3-in. mortar thus became at length an approved service weapon, and in February, 1916, a new demand was received for 2,400 3-in. mortars and ammunition at the rate of 176,000 rounds weekly. Field trials had been completed by 28 March, 1916, when the Commander-in-Chief in France wrote that "all reports agree as to the efficiency of the 3-in. Stokes gun," and notified his intention to substitute it for the existing types of light mortar, viz., the 3·7-in. and the 4-in.

The main defect in the mortar in January, 1916, was a tendency in the tripod mounting to buckle. A modified mounting with legs of commercial-sized tubing was then submitted by the Trench Warfare Research department,[1] and manufacture of the new type of mounting began on the group system in the February following.[2]

(b) Organised Manufacture of Medium Mortars by the Trade.

While the light Stokes mortar was in course of development, a determined effort was being made to produce medium mortars in largely increased numbers. At the end of June, 1915, when the actual number of 2-in. mortars which would eventually be needed still remained uncertain in the mind of the supply authorities, and pending the formal transfer of responsibility for their supply from the Directorate of Artillery to the Trench Warfare Supply department, the Military Secretary to the Ministry of Munitions suggested that a preliminary order should be given for 100 2-in. mortars and 10,000 rounds of ammunition.[3] Accordingly, General Jackson was instructed on 2 July to ascertain how many of these could be supplied by the Ordnance Factory and to obtain the balance from the trade.[4] Manufacture of 2-in. mortars was at once resumed at Woolwich, where work began in the first week of July, about two months having elapsed since the completion of the first twenty-five weapons.[5] Output was at the rate of 10 a week.[6] During the next seven months the Ordnance Factory made in all 103 2-in. mortars. In the meantime, manufacture by the trade was fully organised, and from the beginning of 1916 work on this type of mortar ceased at Woolwich.[7]

The manufacture of 2-in. mortars by the trade presented no great difficulties.[8] A sample mortar was borrowed in July, 1915, from the trench mortar schools of the First Army and was sent to the various districts where shell manufacture was then in course of organisation.[9] About half a dozen local committees offered to make varying numbers. The Joint Railway Executive Committee were prepared to make 50 mortars weekly, stipulating for payment on a cost plus percentage basis. Two makers of agricultural implements proposed to organise the manufacture of from 50 to 100 weekly among a combination of East Anglian firms.[10]

A formal demand was received from the War Office (4 August) for 1,000 medium mortars, of which one-half should be 1·57-in. (Vickers)

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[1] C.R./T.W.D./1120 (7).

[2] See above, p. 19.

[3] C.R./T.W.D./1120 (7).

[4] *Ibid.*

[5] Hist. Rec./H/1610/8, p. 4.

[6] C.R./T.W.D./1120 (1).

[7] Hist. Rec./H/1122.1/3.

[8] Mr. Haigh to Mr. Roger, 22/9/15 (C.R./T.W.D./1120 (1)).

[9] Hist. Rec./H/1610/8, p. 6.

[10] T.W. 1963.

and the other half 2-in., together with ammunition at the rate of 20 rounds apiece daily. It was contrary to the policy of the new department to place a large order for mortars with an armament firm, and it was found impracticable to get rapid deliveries of the costly and complicated 1·57-in. mortar with its special ammunition from any other firm than Vickers,[1] whose existing orders were not then completed. Accordingly, contracts were immediately placed for 800 2-in. mortars; the remaining 200 were of the 1·57-in. type, and were supplied on an order for 50 already placed with Messrs. Vickers by the War Office in July, 1915, and a subsequent continuation order for 150 given by the Ministry of Munitions in the following October.[2]

Although orders were placed for 800 2-in. mortars only, the steel was obtained for 1,000. The mortars were made in railway workshops and by agricultural machinery makers. A scheme for group manufacture was also organised in the Sheffield district. For this purpose the work was divided according to its nature. The timber for the beds was to be cut at Liverpool; the brass casting and machining was divided among nine different firms; constructional steel work was allocated to three firms who made their own templates from a sample; steel forgings for the gun base and base bracket were obtained from five firms, the machining was put out to 25, since there was greater pressure on this class of work; centres were chosen to assemble 250 mortars each.[3] The contracts for the 800 mortars were placed by 18 August, 1915. The first deliveries from railway works began in the following October. Supplies from other sources came forward in the following December.[4] The first 800 trade-built mortars were completed by the end of June, 1916; but actual issue of the last deliveries of mortars was delayed pending the manufacture of the Temple silencer.[5]

An important result of the manufacture of mortars by the trade was the organisation of a system of proof. So long as trench howitzers had been produced only by the Ordnance Factory and Vickers the only tests applied were departmental inspection in the one case and a firing test on the firm's own range in the other. In the autumn of 1915 it was decided to take Vickers' certificate of proof but to prove other trade-made mortars at Woolwich.[6] In the spring of 1916, when mortars and ammunition were coming forward in unprecedented quantities, a distinct proof range was established for trench mortars at Buxton.

In October, 1915, a definite effort was made to regularise the demand for trench mortars and their ammunition. Sir John French asked on 27 October for light, medium and heavy trench mortars on a divisional basis, viz., two batteries of light and one of medium mortars to

[1] D.M.R.S. 262.

[2] C.R./T.W.D./1120 (2).

[3] T.W. 1963.

[4] C.R./T.W.D./1120 (2).

[5] (Printed) *Weekly Report*, No. 47, VII., VIII. (24/6/16).

[6] *Ordnance Board Annual Report*, 1915, p. 305.

each infantry brigade and one battery of heavy mortars to each division. Allowance for wastage was to be calculated at 20 per cent. in view of the forward position of the mortars, which rendered them particularly liable to capture. Ammunition would be required at the rate of 15 rounds daily for light mortars, 10 for medium and 7 for heavy mortars.[1] It was then becoming necessary to obtain a forecast of future requirements in order to ensure economy and the smooth working of supply. Accordingly, in response to a request from the Ministry for information as to the number of divisions to be supplied with trench mortars and the demand for theatres of war other than the Western front, a complete statement of the requirements up to April, 1916, was forwarded on 11 November, 1915,[2] and became the basis of the manufacturing programme until the number of types in use was drastically reduced in the following spring. The new programme involved orders for 75 additional 1·57-in. mortars but no new 2-in. mortars, thus bringing the total requirement of medium mortars to 1,200, inclusive of a reserve.

In mid-July, 1915, when the Ministry of Munitions had become responsible for the supply of all trench mortars, 140 1·57-in. mortars had already been accepted on an order for 150 which had been placed by the War Office in the previous April.[3] The order for 50 more was placed on 20 July, just before the actual transfer of responsibility.[4] These two orders were completed early in the following December.[5] When the requirement for 75 additional mortars was received in November, 1915, the price of this mortar was slightly reduced, but it was still double that of any other produced by the trade.[6] During the winter of 1915-16 various proposals were brought forward for improving the design by lengthening the barrel, re-designing the cumbersome mounting and adopting a new form of ammunition. Supply authorities suggested in consequence that the mortar should be entirely replaced by the 2-in.[7] At the end of the following April, preliminary instructions were given by the Director of Artillery to cease producing this mortar,[8] and shortly afterwards it was withdrawn from France in order to reduce the number of types in the field.[9]

(c) Production of the O.F. Light Mortars.[10]

Little change was made by the Trench Warfare department in the methods already established for producing the two existing types of light mortar, the 3·7-in. and the 4-in. With one exception, the demands received for these between July, 1915, and March, 1916,

[1] D.M.R.S. 262.

[2] Appendix II.

[3] (Printed) *Weekly Report*, No. 1, p. 7; C.R./T.W.D./1120 (2).

[4] C.R./T.W.D./1120 (2).

[5] (Printed) *Weekly Report*, No. 20 (11/12/15).

[6] *Ibid.*, No. 19 (4/12/15).

[7] *Ibid.*, No. 30 (19/2/16).

[8] *Ibid.*, No. 39, VIII. (29/4/16).

[9] See below, p. 61.

[10] Based on Hist. Rec./H/1610/6.

were met by corresponding extracts on the Ordnance Factory. When the department took control, existing requirements for 4-in. mortars had already been met and about 30 had been issued to France.[1] The first new demand for this nature was for 238 additional mortars required to place the light mortars on a divisional basis in November, 1915.[2] The whole number was satisfactorily completed by the Ordnance Factory by the end of April, 1916. The 4-in. mortar was then withdrawn from use and its manufacture ceased entirely.

The 3·7-in. mortar was still required in large numbers during the latter half of 1915. The War Department relied upon this nature for equipping the British forces in the Dardanelles, to which a first instalment of 20 mortars was sent in July, 1915.[3] Informal efforts to supplement these mortars with more satisfactory types, particularly the 3-in. Stokes and the 2-in., met with little success before the withdrawal from Gallipoli in the following November owing chiefly to difficulties experienced in producing sufficient ammunition. Production of the 3·7-in. mortar was at first restricted to the Ordnance Factory. Work on a new order for 100 mortars began there on 20 July, 1915, and an extract for a second hundred was placed on 21 October. When the demand was revised in November, 500 additional 3·7-in. mortars were required to make up the equipment of light mortars. The Ordnance Factory made 150 of these ; the rest were produced by the trade, the department supplying forgings to contractors who machined the barrels and completed the mortars.[4] The last of these went forward for inspection in May, 1916, after which this nature was gradually superseded by the 3-in. Stokes mortar.

III. Organisation of Ammunition Supply, July, 1915—May, 1916.

(*a*) ORGANISATION OF CAPACITY FOR THE EMPTY BOMB.

The production of ammunition constituted a far more difficult problem than the supply of the mortars themselves. The first efforts of the Trench Warfare department were concentrated during the summer of 1915 upon organising among commercial engineers the manufacture of bombs for the 3-in. Stokes and 2-in. mortars which were then being ordered. The "stick-bomb" of the 2-in. mortar consisted of a spherical head of steel or cast-iron with a 22 in. steel stem fitting into the barrel of the mortar. During July orders for about 140,000 cast-iron bombs were placed with numerous iron-founders, the cast-iron pattern being used in order to avoid encroachment on the steel capacity of the country, which was already overtaxed.[5] Certain of these contractors were picked firms chosen by the department ; others were recommended by Boards of Management in response to a general circular.[6] The solid-drawn steel tube

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[1] Appendix I.
[2] Appendix II.
[3] HIST. REC./H/1610/8.
[4] T.W. Contract 2081 ; (Printed) *Weekly Report*, No. 21 (18/12/15).
[5] HIST. REC./H/1610/8.
[6] HIST. REC./R/1610/23.

for the stems was only available from an extremely limited number of firms, one of the largest of which had been under German control at the outbreak of war.[1] Arrangements were made to obtain the whole supply of rough tube from this firm and they eventually undertook to give instructions and help to the contractors responsible for machining and finishing.[2] The loss incurred in machining faulty tubes was borne by the bomb contractors, whose interest in the quality of the tubes used thus became an additional check upon inspection.[3]

In mid-August, 1915, it was decided to supply another half million bombs with a view to providing ammunition for the 800 2-in. mortars then ordered. Contracts or options for 675,000 bombs were placed by 23 August.[4] The price was fixed on a uniform basis so calculated as to allow a fair profit to experienced firms and not to involve the inexperienced in loss. It compared favourably with the price quoted by the Chief Superintendent of Ordnance Factories as the result of the few sub-contracts placed in the early summer. His sub-contractors charged 42s. for each (empty) bomb; whereas the fixed price for the large numbers ordered by the Trench Warfare department was 21s. apiece, a rate subsequently reduced when makers had gained experience.[5]

The initial difficulties of organising manufacture on so large a scale were considerably enhanced by the circumstances under which the work was undertaken. The Ordnance Factory had been making 2-in. bombs in small quantities for a few months only. It was still working on a provisional specification. The new contractors were confused by changes made in the specification when first deliveries were about to become due. Rigidity in the standards of inspection aggravated the difficulty normally experienced by commercial firms in working to exact limits.[6] The enormous expansion in the work of the inspection department led almost inevitably to a mechanical sentencing of bombs and their material by examiners who were not in a position to use discretionary powers. Yet the exercise of some such power was essential to the rapid production of the 2-in. ammunition, for which the existing specification was merely a record of the materials used by the Ordnance Factory in an emergency and not the result of expert knowledge applied under very special conditions, as was the case in drawing up the normal specifications for artillery ammunition. These circumstances affected most strongly the supply of components, which is considered below. They applied also to the weight of the bomb-head, and to the nature of the metal specified for the stem. After considerable delay the staff for inspecting trench mortar ammunition was organised upon lines commensurate to the expanded output. Small quantities of uninspected bombs were available for special purposes in the meantime. Thus, the smoke ammunition issued in emergency for the Battle of Loos included uninspected 2-in. bombs of trade manufacture.

[1] HIST. REC./H/1610/12.
[2] T.W. Contract 2569.
[3] HIST. REC./H/1600/7, p. 4.
[4] T.W. 2766.
[5] HIST. REC./H/1610/8.
[6] C.R./T.W.D./1120 (1).

Certain important changes in the design of the 2-in. bomb were also made at the earnest instance of the supply authorities in order to meet the new conditions of production. The most important of the changes thus effected was the substitution of hot drawn tube, which could be obtained immediately, for the cold drawn tube which had been used in making the stems by the Ordnance Factories, but was not commercially available in the required quantities, although it had the advantage that it did not need machining.[1] The metal originally specified indicated steel of a brittle nature almost approaching tool steel.[2] Various samples of the hot-drawn tube which it was practicable to obtain were tested during August and September, 1915, until at length the firm evolved a form of hot-drawn tubing which would meet the conditions imposed, and was recommended for approval by the Ordnance Board on 13 October.[3] The primary difficulties experienced in building up manufacture had thus been overcome by the first week in October, 1915, when the 2-in. bombs made commercially were first filled in quantity at the Erith filling station.[4]

Production of the 3-in. Stokes bombs was organised simultaneously. The bomb consisted of a cylindrical body made of lapwelded wrought iron or steel tube with end pieces of malleable cast-iron or steel-drop forgings. Attached to the base was a small perforated steel tube bored out to contain the propellant cartridge, which was fired by the concussion when the bomb was slipped down the barrel on to a striker pin screwed centrally into the closed end of the mortar. The main difficulty in production was again the supply of tubing. The remaining processes could be carried out in most general engineering shops.[5] The tubing was all provided by a single established firm of tube makers and was of satisfactory quality, rejections in the seven and a half million tubes produced during the first two years of production being at the rate of 2 per cent. only.[6] The castings and stampings were also bought centrally and supplied to contractors.[7]

Two important factors delayed the output of bombs during the autumn of 1915. In the first place, drawings and specifications were not in form for issue to contractors until 28 September, and even then the design of fuse had not been settled.[8] Inquiries had in the meantime been made with a view to obtaining the ammunition sanctioned by Mr. Lloyd George on 12 August. Provisional orders for 5,000 bombs weekly were placed on 16 August, and on 27 August the local munition committees were invited to inspect such drawings

1 HIST. REC./H/1600/7.
2 T.W. 2770.
3 *Ordnance Board Annual Report*, 1915, pp. 438–440; HIST. REC./H/1600/7. pp. 3, 4.
4 Appendix VI.
5 Sec./Gen./1013.
6 HIST. REC./H/1610/6.
7 HIST. REC./R/263.6/23.
8 HIST. REC./H/1611/1.

and specifications as then existed. During this period, however, the modifications in design which were being brought forward daily added to the difficulty experienced by the firms concerned in starting up a new class of manufacture. These constant changes inflated very considerably the prices asked by manufacturers. Although the cost of the material used was only 3s. 9d. the prices asked ranged between 14s. 6d. and 19s. 6d., in view of the numerous and conflicting instructions given as to methods of manufacture.[1] Another disadvantage, even graver at the time, was the fact that these modifications seriously delayed the output anticipated.

The second factor in delaying immediate output was the problem of obtaining in sufficient numbers the gauges required for inspection.[2] This depended upon the settlement of the design for the empty bomb, which was not effected till the end of September. In order to avoid competition with the general requirements for gun ammunition gauges, the Trench Warfare department set up its own sources of supply, using firms unaccustomed to this class of work, and sending gauges to the National Physical Laboratory to be tested. By this means a sufficient number was eventually obtained to enable inspection to take place at works.[3]

Contracts were placed with numerous small firms, and with a few larger firms, in order to stabilise production. The output of the smallest shops was utilised by means of co-operative schemes arranged through the local munitions committees. Thus, orders were given in 1915 to eighteen firms within the Blackburn district, and a single agreement in this district represented the output of four shops ranging from 25 to 100 bombs weekly as well as that of the nominal contractor. The orders first placed covered periods extending from twelve to twenty weeks; but it was considered desirable in renewing contracts to synchronise their termination, so that any changes in price should be uniform.[4]

Owing to the initial difficulties described above, the output of 3-in. bombs was at first considered extremely unsatisfactory, and compared unfavourably with the large and immediate production which had at first been anticipated. Orders had been placed for about 800,000 bombs by 4 October, 1915, when a special effort was made to hasten production in order to despatch large numbers to the Dardanelles by mid-November. These bombs were to have been issued with fuse-heads of the original pattern, already ordered in large quantities. An engineer was specially appointed to keep track of the work on empty bombs, and provision was made for the components necessary to complete the rounds. In the middle of October filling began at the Trench Warfare factories, but the first ammunition sent for trial on 15 November was still regarded as extremely unsatisfactory.[5]

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1 Hist. Rec./H/1610/6.

2 Hist. Rec./H/1611/1.

3 Hist. Rec./H/1610/6; (Printed) *Weekly Report*, No. 19 (4/12/15).

4 Hist. Rec./H/1610/6.

5 *Ordnance Board Annual Report*, 1915, p. 436.

Rejections had been numerous on the first deliveries of empty bombs which had just begun to come forward[1]; but the number of defects was speedily reduced by a system of testing established at the Fulham filling factory, where contractors' representatives received instruction and advice as to defects in their sample bombs.[2] In this way the first manufacturing difficulties were overcome before January, 1916, when satisfactory trials took place, upon the results of which issue of the ammunition was then sanctioned.

Thus during the latter half of 1915 manufacture of 2-in. bomb-shells by the trade was gradually built up on a large scale to succeed the comparatively slow production of the Ordnance Factory, and the 3-in. Stokes bomb was obtained from commercial sources alone. Of the two Ordnance Factory patterns, production of the one type (the 3·7-in.) had already been begun by a single contractor when the Trench Warfare department became responsible for supply in the summer of 1915. The total output of this nature was then 5,000 weekly. The whole of the extra supply of ammunition for the 100 3·7-in. mortars which the Ordnance Factory began to produce in October, 1915, was obtained from the same contractor, and deliveries had reached 15,000 weekly by May, 1916, when the use of this type of mortar was cancelled.[3] Until November, 1915, manufacture of the 4-in. bomb had been restricted to the Ordnance Factory, where output was at the rate of 200 weekly.[4] The revised demand then raised this requirement to 6,300 weekly in December, rising to 19,250 in the following April.[5] To expedite delivery it was proposed to substitute a cast-iron studless bomb for the existing pattern of studded steel. Some weeks of experiment evolved a cast-iron bomb with studs to take the rifling. Pending the result of these investigations no contracts were placed. In February, 1916, orders were eventually given for the new type of studded bomb.[6] Deliveries on these began to come forward in the middle of April, when it was arranged to fill both the bombs made at the Ordnance Factory and those produced by the trade at the Watford filling factory.[7] The cessation of the demand for this type of mortar took place a month later, before any of the cast-iron bombs made by the trade had been despatched overseas; small quantities of these were, however, issued for Home Service.[8]

(b) CREATION OF FILLING CAPACITY.

The Ordnance Factory was entirely responsible for filling bombs of its own manufacture, and Vickers for filling 1·57-in. bombs, until the arrangement for loading all 4-in. bombs at Watford was

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[1] (Printed) *Weekly Report*, No. 14 (30/10/15).
[2] *Ibid.*, No. 18 (27/11/15).
[3] HIST. REC./H/1610/16; T.W. Contract 1718.
[4] C.R./T.W.D./1120.
[5] Appendix II.
[6] (Printed) *Weekly Report*, No. 28 (5/2/16).
[7] *Ibid.*, No. 38, VII. (22/4/16).
[8] HIST. REC./H/1610/16.

made in the spring of 1916. The construction of new filling factories in the autumn of 1915 to deal with the bomb-shells produced by the trade has been described above.[1] The filling of 2-in. bombs began at Erith on 9 October, 1915, and by the end of the year all the factories planned in the previous August were in good working order. During the period under consideration (July, 1915, to May, 1916) the chief difficulties experienced were the delays due to shortage of inspectors and the accumulation at the filling factories of large numbers of bombs awaiting completion. The factories had been organised not only for filling the empty bomb, but also for packing the filled bombs into boxes together with their fuses, detonators, and other components for direct issue overseas. It was a characteristic feature of the system initiated by the Trench Warfare department that all trench mortar ammunition should be issued in complete rounds. Any shortage of components thus tended to produce congestion at the filling factories and also involved much rehandling of the stores. On the other hand, this method of issue made all ammunition ready for use the moment it reached the troops, and diminished congestion in the trenches themselves, where any accumulation of stores would have been of much graver consequence than at the factories.

(c) The Supply of Components.

From the inception of trench warfare until the spring of 1916 the design and supply of fuses and other components lagged behind those of the bomb itself and caused serious delay in the output of the complete round.[2] Since the production of mortars was regulated by the ammunition available, the development of a fuse which should be efficient, safe, and capable of rapid manufacture was of primary importance in supplying the armies with this class of weapon. The types of mortar produced by the Ordnance Factory to meet the emergencies of 1914-15 were provided with components which were then immediately available. For instance, the propellant used with the 2-in. mortar was (blank) tubular cordite, size 15-13, which was remaining from recent manoeuvres. Its reproduction was undesirable, since it would displace double the amount of rifle cordite, and it therefore became necessary to provide a substitute.[3] Again, the fuses first issued with mortar ammunition were modifications of artillery fuses, of which the numbers available to meet the gun ammunition programme were strictly limited. Thus the first 2-in. and 4-in. bombs were issued with fuse No. 27 (or 65A), a modification of No. 65, which was in demand for Admiralty purposes and for the 15-pdr. Land Service shells. From the first its use for trench mortar ammunition was considered undesirable, and in May, 1915, the Chief Superintendent of Ordnance Factories had reported that its production was the main difficulty in the manufacture of trench mortar ammunition[4]; but no alternative had been found when the Trench Warfare

[1] See above, p. 23.
[2] Hist. Rec./H/1600/9, p. 25.
[3] (Printed) *Weekly Report*, No. 10 (2/10/15).
[4] *Ordnance Board Annual Report*, 1915, pp. 150, 152.

department undertook to expand the supply of bombs for the 2-in. mortar.[1] Towards the end of July, 1915, reports from France showed that even the No. 27 was inefficient with this nature.[2] It was therefore retained for the 4-in. mortars only, while arrangements were made to issue fuse No. 31 in limited numbers (up to 2,000 weekly) for 2-in. ammunition. This was a simple conversion of fuse No. 80, the time fuse in greatest demand for gun ammunition. Its use had already been proposed on 9 July, 1915, by the Chief Superintendent of Ordnance Factories, who then anticipated that its trials would take some time.[3] Early in September, 1915, the Trench Warfare department arranged to obtain a further number (15,000) of fuses No. 31 from the Ordnance Factory pending the evolution of a simply designed fuse suitable for rapid manufacture.[4] At the end of November it was calculated that the Ordnance Factory's output during the next two months would still fall short of the total deliveries of empty 2-in. bombs by 10,000. Moreover, this estimate apparently made no allowance for the 4-in. ammunition, which was fused with either No. 27 or No. 31A, and was being produced at the rate of 200 weekly. The production of fuse No. 31A was very costly. It could be effected with some economy by using defective No. 80 fuses; but the process of conversion was awkward, dangerous and slow. However, no other provision existed at the end of 1915 for fusing the trench mortar ammunition, which the factories newly established by the Trench Warfare department were about to turn out in largely increasing quantities.

An obvious solution to the problem was the development of a new and simple design of fuse specially suited to the conditions peculiar to trench mortar ammunition (*e.g.*, the extremely low set-back on discharge), and in consequence capable of rapid manufacture. The Director of Artillery had suggested (about 2 June, 1915) either that a simple form of fuse should be designed or that the fuse from the Vickers mortar should be adopted.[5] From July till November, 1915, trials and experiments were in hand with a simple design of percussion fuse evolved in the Royal Laboratory for this purpose (R.L. design 21,400).[6] In the meantime the general use of the Vickers fuse had proved impracticable. In the time fuse first issued with the 1·57-in. ammunition the limits of safety were low until certain modifications were introduced in the following August.[7] Even then the fuse was specially difficult to supply, since the greater part of the output was absorbed by the Admiralty for anti-aircraft purposes.[8]

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[1] See Appendix I.
[2] *Ordnance Board Annual Report*, 1915, p. 151.
[3] T.W. 1158.
[4] C.R./T.W.D./1120 (1); T.W. 2768.
[5] *Ordnance Board Annual Report*, 1915, p. 152.
[6] *Ibid.*, p. 153.
[7] *Ibid.*, p. 157.
[8] *Ibid.*, p. 153; HIST. REC./R/900/8.

All the medium mortar ammunition issued with the modified time fuses described above was giving unsatisfactory results, both by reason of large percentages of blinds and because the craters formed by the bombs were obstacles almost as difficult to negotiate as the wire which the mortars were intended to destroy.[1] Sir John French wrote[2] on 27 October, 1915, as follows :—

> "At present no percussion fuze is provided, and the time fuzes in use with the medium mortars are so far very unsatisfactory. If they cannot be improved so as to give satisfactory results it will be necessary to consider whether the type of bomb for these mortars should not be altered to the 'aerial torpedo' type with wings, so as to permit of the use of a percussion fuze."

The position had not been improved when in December, 1915, the newly-formed Design department of the Ministry undertook to make a new start in evolving fuses for mortar ammunition.[3] Several patterns of simplified fuses were at once considered by the Ordnance Committee. Two of these, the "Sutton" (No. 28) and an R.L. design (No. 21930), were time fuses ; two were percussion fuses, the one the "Boase" (fuse No. 105), for graze effect, the other the "Newton," for either instantaneous or crater effects. The Trench Warfare department had given provisional orders for 5,000 of the Sutton fuse in anticipation of its approval ; but trials had been delayed pending the manufacture of experimental supplies. Three of these comparatively cheap and simple fuses, the Sutton, Boase and Newton, were sanctioned for use with the 2-in. and 1·57-in. mortars during the first fortnight in February.[4] The issue of trench mortar ammunition was then seriously restricted by the supply of fuses. Extraordinary efforts were made to hasten the production of the new types. Outside engineers made special visits to the manufacturing districts concerned, and speedy deliveries were encouraged by a system of bonuses on early deliveries of the first 150,000 Boase and Newton fuses ordered.[5] The new fuses began to come forward early in March, 1916, and the supply of this component soon ceased to limit the output of completed ammunition, which was issued during the transitional period with No. 31, Boase and Newton fuses, and subsequently with 75 per cent. Newton, and 25 per cent. Boase, fuses.[6]

In the meantime delays in obtaining other components had also been overcome by special arrangements. Thus the output of propellant charges for the medium mortar had been set on a satisfactory footing by the establishment of entirely new sources of supply. The adoption of a commercial detonator in the exploder for the

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[1] Hist. Rec./H/1600/14 ; "The 6-in. Newton," p. 2.

[2] D.M.R.S. 262.

[3] Hist. Rec./R/900/8.

[4] (Printed) *Weekly Report*, No. 28, VII. (5/2/16) ; D.G.M.D./M/2.

[5] T.W. 4189.

[6] D.M.R.S. 337.

2-in. bomb had also facilitated rapid production.[1] A brass exploder-pocket was evolved to allow filling to be effected with ammonal in powder form. These pockets were issued in considerable quantities before the design was formally sanctioned. One of the gravest difficulties in connection with the 2-in. trench mortar arose out of the general shortage of capacity for the T friction tubes for ignition. Existing capacity was insufficient for the needs of the regular artillery. After a delay of two months, it was decided to adopt the supply officer's proposal that the use of the T tube should be abandoned and the 2-in. mortars fitted with rifle breech mechanisms similar to those used with the lighter natures.

In the case of the Stokes mortar[2] also the development of a satisfactory detonating system had been the prime difficulty in the development of design, and the production of fuses had seriously affected supply. The first sanction to produce the mortar and its ammunition was conditional upon the development of a satisfactory fuse. The safety of the special igniting apparatus which had been adapted from the Mills grenade was called into question shortly after the mortar had been approved for service use at the end of August, 1915. Experiments were continued throughout the autumn with a view to improving this form of fuse.[3] First deliveries of an improved type were made early in December, and issues of ammunition so fused began under provisional approval given early in January, 1916. The fuse was simple and capable of manufacture by the trade. It consisted of a central-fire cartridge head and Bickford fuse. Its main disadvantage was that its use entailed the cutting of Bickford fuse in the field.[4] It was not until the following year that it began to be superseded by various types of "Allways" fuse.[5]

During the winter of 1915-16 the measures which had been taken to organise the output of trench mortar ammunition in proportion to the needs of the growing Army began to give tangible results, which reached their climax in the spring of 1916. The total output of high explosive ammunition for trench mortars attained during the second quarter of 1916 was, in fact, never exceeded in any single quarter throughout the war. Over two million rounds of mortar ammunition were completed during the three months ending in June, 1916, as compared with rather less than 50,000 produced in the corresponding quarter of the previous year.[6] These figures in themselves do not represent the whole of the achievement. More than 75 per cent. of the mortar ammunition issued in the spring of 1915 had been for the 3·7-in. trench howitzer, a weapon which was notoriously unsatisfactory. The development of the 3-in. Stokes mortar and the increase of 2-in. ammunition to between three and four hundredfold of the output in the previous spring reduced the proportion of this unsatisfactory ammunition to less than 18 per cent. of the whole.

[1] See above, p. 16.

[2] HIST. REC./H/1611/1.

[3] (Printed) *Weekly Report*, No. 17 (20/11/15).

[4] HIST. REC./R/900/8.

[5] See below, p. 68.

[6] Appendix XI.

Again, the methods used in getting these results were definitely calculated to avoid unnecessary encroachment upon other essential munitions of war, and particularly to leave free all the capacity available for the manufacture of gun ammunition. What plant could be spared from shell production by the Ordnance Factory and one armament firm had been utilised during the first year of trench warfare and remained practically the sole source of supply until the last quarter of 1915. The first deliveries of trade-made ammunition for the 2-in. and the 3-in. (Stokes) mortars then turned the balance of production in favour of the new sources of supply from which all mortar ammunition was eventually to be obtained.

IV. The Introduction of a Heavy Mortar.

The mortars produced during 1915 were all either light or medium in class, the heaviest bomb, viz., that thrown by the 2-in., weighing 50 lb. Towards the end of June, 1915, there was some demand for a heavier mortar, throwing, if possible, a 100-lb. projectile; but opinion differed as to the utility of such a weapon. Some considered that it would greatly relieve the large howitzer; others thought that bombs weighing more than 50 lb. could not be conveniently handled in the trenches, and that efforts should be concentrated upon reproducing the light and medium mortars of the types then existing.[1]

Among the *desiderata* which Sir John French had named in first asking for the supply of trench mortars was great shell-power combined with mobility. An experimental 5-in. trench howitzer, designed by Messrs. Armstrong, had been sent out by the Army Council in December, 1914, "in the hope that it could do what the 4·5-in. howitzer could not with safety, viz., fire at the enemy's trenches within 100 yd. of the British line." It fired a 5-in. howitzer shell, but was found unsuitable for conditions in the trenches, and, in fact, after 14 hours had been spent upon its emplacement, it became so clogged with mud that not a single round could be fired.[2] In January, 1915, General Headquarters, France, had emphasised the need for two types of mortar, the one light, the other throwing heavy shell and similar in power to the German *minenwerfer*.[3] The 2-in. mortar was the heaviest British type developed by the summer of 1915. In the meantime a French firm had evolved a heavier trench howitzer, viz., the 240 mm. This mortar threw a 190-lb. bomb and itself weighed 34 cwt., while certain of its parts weighed 5 cwt. Hence it was strictly limited as to mobility.[4]

(*a*) DEVELOPMENT OF THE 9·45-IN. MORTAR.

In September, 1915, Mr. Lloyd George borrowed from M. Albert Thomas drawings of certain types of French mortars, taking a keen personal interest in their adoption by the British Army. These drawings, which were forwarded to the Director-General of the Trench Warfare

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[1] Gen. I. Philipps to Dr. Addison, 30/6/15 (C.R./T.W.D./1120 (7)).

[2] 121/Stores/970. [3] 121/Stores/1554. [4] D.M.R.S. 262, B. 9.

department about 20 September, included particulars of the heavy 240 mm. mortar, and also of the "Dumézil" 58 mm. mortar, which could throw a light (35 lb.) or a heavy (100 lb.) bomb.[1] A demand had already been received on 5 September from the Mediterranean forces for 24 "Dumézil" mortars with ammunition of both kinds. General Jackson reported on 22 September that the two patterns described above were worthy of consideration, and arrangements were made for studying their use in France and for borrowing specimens, which were brought to England on 29 October, 1915.[2]

During the autumn of 1915 the types of mortar to be used in France were reconsidered, and Sir John French notified on 27 October that a heavy mortar was urgently needed in addition to the light and medium mortars in existence. He considered that the choice rested between evolving a 150-lb. stick bomb for use with the 4·5-in. howitzer or adopting the 240 mm. French mortar, or developing a heavier design of mortar along the lines of the existing 2-in. There were considerable objections to the use of a stick bomb with the 4·5-in. howitzer. There were not enough of these weapons to spare, and the flash was likely to reveal the position of the howitzers and to draw fire. It was thought that less time would be taken in copying the French mortar than in evolving an entirely new design. He therefore recommended that this course should be adopted, desiring to be supplied with one heavy mortar to each division and a ration of seven rounds per mortar per day, and asking for the winged type of bomb, or at least some pattern which should admit of a percussion fuse. The range should be at least 1,000 yards.[3]

The sample 240 mm. trench howitzer obtained from France had a maximum range of 1,100 metres. Its bomb shell weighed 100 kg., and contained 50 kg. of high explosive. Four fins or vanes attached to the base of the bomb ensured its falling upon its head, and therefore allowed of the use of a percussion fuse. The mortar with its bed formed three loads, which were moved on two-wheeled steel-framed hand-barrows.[4]

The decision to copy this pattern had been taken with a view to expediting production; in practice, the manufacture of replicas of the sample howitzer and its ammunition was considerably delayed by difficulties in obtaining the exact material used by the French and by differences in the conditions of manufacture in France and England, particularly by delays in procuring a suitable propellant to replace the spiral powder used by the French, and by the need for organising welding capacity on the scale required.

The British Government purchased the right to reproduce, and the Trench Warfare department's representatives investigated French methods of manufacture. The first difficulty arose in obtaining steel for the barrel. The specification drawn up by the inspection authority as a result of analysis demanded a percentage of carbon difficult to

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[1] HIST. REC./R/1610/22.

[2] *Ibid.*

[3] D.M.R.S. 262.

[4] *Ordnance Board Minutes*, 16765.

procure, although the French firm's specification recommended "the ordinary quality of steel for guns."[1] The problem was solved by using picked billets only. At the suggestion of Sir William Weir, it was arranged to punch the barrels in a manner similar to that used in making shell. Some delay resulted from the adoption of a novel process; but it was considered that still greater delay would have arisen had the barrels been produced by armament firms in competition with ordnance.[2]

Towards the end of December, 1915, trial orders for fifty bombs each were placed with six firms.[3] The trial bombs were to be delivered by the end of January. Their manufacture entailed a considerable amount of welding, a class of work quite new to five out of the six firms.[4] Other contractors were subsequently added. The chief difficulty experienced in organising the welding was increased by a delay of some months in obtaining the trained instructors from France.[5] In order to reduce the amount of welding involved, an experimental order was given for manufacture on the bottle system; but the use of this method was restricted by demands on the same plant for making gas-bottles.[6] Trial orders were placed on a cost plus percentage basis, and contractors were allowed to experiment with other systems of manufacture, but at their own cost and on the understanding that output by the methods recommended should not thereby be prejudiced.[7] During February, 1916, provisional orders for bulk supplies were placed with certain of the firms chosen in view of their success with the trial orders, and the contractors began laying out shops for this purpose.[8] The department subsidised one firm, contributing rather more than half the estimated cost of the new factory, which was to be entirely devoted to the manufacture of these bombs. The capital contributed by the Ministry was payable in instalments by a fixed sum added to the price of each bomb delivered. It was stipulated that output should be chiefly attained by female labour, and that the handling plant should be arranged accordingly.[9] Assembling factories were organised, and a new filling station was erected at Watford by the Trench Warfare department, experimental bombs being in the meantime loaded at existing filling factories.

Approval of the use of ammonal and 80/20 amatol, British high explosives which were available for the bursting charge, was given early in February.[10] The fuse at first sanctioned was the time fuse in use with other mortar ammunition, viz., the No. 31.A. Towards the

[1] (Printed) *Weekly Report*, No. 19 (4/12/15).
[2] Hist. Rec./H/1600/7, p. 6.
[3] Trench Warfare Contracts 2018-2023.
[4] Hist. Rec./H/1600/11, p. 13.
[5] (Printed) *Weekly Report*, No. 37; VII. (8/4/16).
[6] *Ibid.*, No. 28, III. (5/2/16).
[7] Trench Warfare Contract 2535.
[8] (Printed) *Weekly Report*, No. 29, III. (12/2/16).
[9] Trench Warfare Contract 3057.
[10] (Printed) *Weekly Report*, No. 28, VII. (5/2/16).

end of February a special effort was made to produce a few heavy mortars and ammunition for overseas supply in March, in order to supplement 12 howitzers and certain ammunition which had been provided by the French Government. Advance approval was given for the use of the 2-in. design of exploder with trade-detonator for this purpose, and the first four mortars were completed by 18 March, 1916. Empty bombs were being delivered to filling stations at the rate of 100 daily by the end of March. The attempt to hasten output was then entirely checked by the failure of the propellant powder, M.D.T. cordite 15-13, which had originally been approved as a substitute for the French spiral powder, pending attempts to reproduce the French propellant. Trials with the approved cordite cartridge towards the end of March gave extremely erratic results. While a new form of propellant was under consideration it was impracticable either to prove the mortars as they came forward or to test the bombs in order to judge adequately of the methods of manufacture which were being used. Eventually, after another three months' investigation, provisional approval of the use of M.D.T. cordite fired by a small arms cartridge was given for the purpose of an urgent overseas demand at the end of June, 1916.[1]

In the meantime one of the firms experimenting had perfected a system of bomb manufacture by two deep stampings, and was prepared to educate other firms in this method.[2] Early in May four expert welders arrived from France, remaining in England for a month to give instruction to the English welders, whose work immediately improved.[3] Accordingly, final arrangements for bulk supply were made with successful contractors in June, 1916.[4]

Thus by the end of June the British 9·45-in. Mark I mortar had been evolved on the model of the French 240-mm. mortar. It had a comparatively short barrel with a maximum range of 1,150 yd. It fired a vaned bomb of steel weighing between 150 and 154 lb., and commonly called the "Flying Pig." The bursting charge was ammonal or amatol 80/20, fused with a No. 31 time fuse. Subsequently a percussion fuse No. 105 (the Boase) was adopted, and later either the French percussion fuse (No. 134) or fuse No. 110 with and without delay. First issues of this mortar were made overseas during the third week of June, 1916, when 30 mortars were despatched with all the ammunition available.[5]

(*b*) UNCERTAINTY AS TO THE REQUIREMENT.

During the whole of the eight months occupied in developing the design and production of the 9·45-in. mortar, the question of the

[1] T.W. 5006; D.G.M.D./G/217; HIST. REC./R/900/8; cf. (Printed) *Weekly Reports, passim.*

[2] (Printed) *Weekly Report,* No. 40, VII. (6/5/16).

[3] *Ibid.*, No. 41, VII. (13/5/16).

[4] Trench Warfare Contracts 3057, 3075, etc.

[5] (Printed) *Weekly Report,* No. 46, VII. (17/6/16); No. 47, VII. (24/6/16).

numbers to be ordered or even of the exact nature of the heavy mortar to be supplied was subject to more than ordinary uncertainty. Firstly, there was under consideration the substitution of a modification of the 240-mm. with a longer barrel to increase range, which had been introduced by the French while the 9·45-in. Mark I was in course of development. A British pattern on these lines was afterwards adopted as the 9·45-in. Mark III.[1] Again, the practicability of using a stick-bomb with the 4·5-in. howitzer remained under consideration, and trial bombs were manufactured for the purpose ; but in March, 1916, General Headquarters, France, laid it down definitely that, even should these bombs be put into use, their production should be considered apart from the supply of heavy mortars.[2]

Four hundred heavy mortars were originally demanded by the War Office in November, 1915, to equip each division with one battery and allow a large margin for wastage. The 240-mm. was accepted as the standard heavy mortar early in December, but, in view of the novelty of the weapon, the orders placed for this type during the winter of 1915-16 amounted only to 200 mortars and 154,370 rounds of ammunition, the total commitments for these being £640,000, exclusive of capital expenditure on the filling factory. Early in February, 1916, the Minister notified the Army Council that trials with the sample 240-mm. trench howitzer had shown it to be very defective in accuracy and that its weight would probably limit its use to positions close to roads. He therefore proposed to place no further orders until further knowledge could be obtained of alternative weapons, viz., the improved type of 240-mm. mortar under trial by the French Government and the stick bombs for use with the 4·5-in. howitzer. On 6 March, 1916, the G.O.C., B.E.F., expressed grave doubts as to the suitability of the 240-mm. mortar either for open warfare or for use in the trenches on account of its weight, suggesting the substitution of the Sutton-Armstrong mortar. After discussion with a representative of the Design department, he asked that the remaining 200 heavy mortars to be provided should be either Sutton-Armstrong mortars or of some other type, which could be brought up through the ordinary communication trenches and would fire a bomb weighing over 100 lb. at least 1,000 yd.[3]

The Sutton-Armstrong mortar had been evolved by Lieut. F. A. Sutton, late of the Trench Warfare department, in conjunction with Messrs. Armstrong Whitworth & Co. The Munitions Inventions department had reported favourably upon it on 8 March, 1916.[4] Preliminary orders for 25 mortars each were placed in June, 1916, with Armstrong Whitworth and with a second firm which had heavy locomotive plant suited to the production of certain parts. During the next six months the design still remained in an experimental stage, the main problem being to secure the range asked by General

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[1] See below, p. 67.

[2] D.M.R.S. 262.

[3] D.M.R.S. 262, 262 B.9.

[4] D.G.M.D./G/269 ; T.W. 2769/228.

Headquarters without sacrificing accuracy.[1] Finally, on 12 January, 1917, this type of heavy mortar was definitely rejected as unsuitable in range, weight of bomb, and rate of fire, while it was complex in design and unsafe in respect of the action of its bomb-stems.[2] The 9·45-in. mortar thus remained the standard type of heavy trench howitzer.

V. Reduction in the Number of Types.

(a) ELIMINATION OF THREE TYPES, MAY, 1916.

The production of a heavy trench howitzer completed the equipment of the British forces with the three classes required. By May, 1916, there existed in service use three types of light mortar (the 3-in. Stokes, 4-in. and 3·7-in.), two medium types (the 2-in. and the 1·57-in.), and a heavy mortar. Moreover, the chief difficulty as to design had been overcome by the development of efficient fuses which could be readily manufactured. The main problems in organising supply had been overcome, and output of the ammunition, which was the controlling factor in mortar production, had been set upon a firm basis in the case of light and medium mortars and was reaching regularity in the case of the heavy mortar.

Multiplication of types had always been regarded as a disadvantage. It complicated unnecessarily the issue of stores; it confused the hurriedly-trained personnel of the new armies. These considerations had led to the rejection of the 3-in. Stokes mortar in the first instance. When the exigencies of supply had brought about the manufacture of this mortar and its ammunition in numbers exceeding anticipation, and when its efficiency and advantages had been tested in the field, decision was taken to rely upon this type alone as the standard light mortar and to eliminate the 4-in. and 3·7-in. This decision was based upon an essential change in the conditions in the field. The supply of munitions had at length outpaced the supply of men. In insisting upon the change, in spite of its apparent wastefulness, General Headquarters, France, stated,[3] that "the limiting factor being now *personnel* and not *matériel*, it is essential that the weapons selected should be those best suited to the tasks they will be called on to perform." Similarly, since the output of 2-in. mortars and ammunition was rapidly increasing, it was decided to withdraw the 1·57-in. mortar from use. This policy had been under consideration for some months. It was definitely outlined by the General Officer Commanding, France, in a letter of 2 May, 1916.[4] He requested the immediate withdrawal of all 4-in. mortars and their ammunition, retaining in reserve the 3·7-in. and Vickers mortars already in France with the existing stocks of ammunition, and recommending the immediate discontinuance of the manufacture of these three types of ammunition. Thus he would substitute the 3-in. Stokes mortar as the standard

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[1] HIST. REC. /H/1610/15.

[2] D.G.M.D./G/269; T.W. 2769/228.

[3] D.M.R.S. 262, B. 3.

[4] D.M.R.S. 262.

light mortar for the 4-in. mortar immediately and for the 3·7-in. mortar gradually, and would replace the 1·57-in. mortar by the 2-in. as the standard medium type.

The result of this decision was to simplify considerably the equipment of the troops and to facilitate future manufacture. At the same time, the sudden withdrawal of three types of mortars at a time when trade-production was attaining regular output on a large scale gave rise to serious financial loss in addition to dislocating capacity.

(*b*) Surpluses and their Disposal.

The decision to cease issue of the 3·7-in., 4-in., and Vickers mortars reached the Trench Warfare Supply department on 26 May, 1916, just as production had been completely organised to meet the full requirements of the previous November. Delivery of 500 3·7-in. mortars had been completed. The output of 3·7-in. ammunition had reached the maximum required, viz., 60,000 weekly. Manufacturers had overcome the initial difficulties in making bombs of this nature by the previous March; but no attempt had been made to exceed existing rates in view of the anticipated withdrawal of this mortar. As it was, 500,000 surplus bombs were left in stock. With the exception of 25,000 issued to home stations no further use was found for these, and they were eventually broken down in order to salve their component parts. By the third week of October, 1916, no 3·7-in. mortars were left in France.

Again, out of 300 4-in. trench howitzers manufactured 168 only were sent to France, the rest being issued to home stations with 65,000 rounds of the cast-iron bombs which had been devised to facilitate manufacture. The new contractors had just begun to make satisfactory deliveries of this type of ammunition when their contracts were closed down in the summer of 1916.[1] No ammunition of this nature remained in France after the first week of July, 1916.

When notification of the withdrawal of the 1·57-in. mortar was received in April, 1916, about two-thirds of the 75 weapons then on order had been produced. After some negotiation, the remaining mortars due on the contract were finally accepted, the whole number being delivered by the second week of August, 1916.[2] It was not until January, 1917, that the last of these mortars was withdrawn from France.

It was agreed in June, 1916, that, when it was possible to do so without affecting deliveries to the British forces, such surplus trench warfare stores should be disposed of to the Allies.[3] Certain patterns, *e.g.*, the 3·7-in. mortar, were, however, unacceptable to the Allied armies.[4] Again, in 1917, certain steps were taken by the Admiralty to utilise surplus trench mortars, particularly the 1·57-in., for arming merchant vessels.

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[1] Hist. Rec./H/1610/16.

[2] (Printed) *Weekly Report*, No. 54, VIII. (12/8/16).

[3] D.M.R.S. 262.

[4] Hist. Rec./H/1610/16.

VI. Maintenance of Output and Development of Design, 1916-18.

(a) REVISIONS IN THE PROGRAMME.

The establishment which had been desired in the autumn of 1915 was six batteries of light, three of medium, and one of heavy, trench mortars per division. The demand was calculated for 100 divisions, instead of for the 70 divisions actually under equipment, in order to allow a large margin for wastage. Ammunition was required for 70 divisions rationed at 15 rounds per mortar per day for light mortars, 10 rounds per day for medium, and 7 rounds per day for heavy, mortars.[1]

On this basis very large stocks were accumulated in France during the first half of 1916. The experience of the summer offensive showed that the occasions for the use of trench mortars were more limited than had been supposed. Thus it was reported in September, 1916, that the only trench mortar which had been used appreciably since the Battle of the Somme began was the 3-in. Stokes, and that the rôle of the medium and heavy mortars was certainly restricted to trench warfare proper and to the preliminary stages of an attack.[2] Expenditure of bombs was limited by transport difficulties in the trenches. The Stokes mortar alone was sufficiently mobile to be carried forward with the attacking forces over difficult ground.[3] A similar view was held by certain French authorities as the result of the great artillery contest at Verdun. These regarded trench mortars as "cheap and inferior artillery," no more accurate than guns and howitzers in spite of their short range, and having the great disadvantage of being "more difficult to place in position, more difficult to supply with ammunition, and more subject to casualties." Against these drawbacks it was, however, admitted that trench mortars had the merits of cheapness, facility of manufacture, and ability to use material and explosives unsuitable for artillery.[4]

In the late summer of 1916 the demand for trench mortar ammunition was therefore drastically reduced. During the following autumn and winter the weekly ration for the 3-in. Stokes was decreased from 176,000 to 75,000 rounds, and for the 2-in. from 68,000 to 20,000 rounds, while for the 9·45-in. it was restricted to 2,500 rounds. Owing to the accumulation of large stocks of 2-in. bombs, contracts for this nature were cut down in August, 1916,[5] and all contracts were terminated early in December[6] In the meantime manufacture of the mortars themselves had progressed regularly. Production of the first 200 9·45-in. mortars was complete by the end of 1916, and the supply of a longer type (Mark II) had just begun for export to Russia.[7]

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1 D.M.R.S. 262.
2 HIST. REC./R/1000/30.
3 C.R./T.W.D./1120 (5).
4 *Ibid.*
5 (Printed) *Weekly Report*, No. 56, VII. (26/8/16) ; HIST. REC./H/1610/11.
6 *Ibid.*, No. 71, VII. (9/12/16).
7 *Ibid.*, No. 73, VI. (30/12/16).

The replacement of the original tripod 3-in. Stokes mounting by the improved tubular type was effected by the end of October, 1916.[1] Requirements for the 3-in. Stokes were raised to a total of 3,000 mortars in August, 1916, and this demand, as well as that for the 1,200 2-in. mortars, had almost been met by the beginning of December, 1916, when an additional demand was received for 500 of the one and 1,000 of the other.[2] In the case of the 2-in., the howitzers were so urgently required, and machining capacity was already so fully taken up with important Government work, that considerable difficulty was experienced in placing orders. These conditions were met by spreading the contracts among a large number of firms.[3]

When the supply of the additional 1,000 3-in. mortars was completed, in the spring of 1917, arrangements were made to continue production at the rate of 200 mortars monthly, subsequently increased to 300 monthly. Increasing numbers of these mortars were then being issued to the East, and the demand for ammunition was again correspondingly increased to 95,000 rounds weekly in June, 1917. Arrangements were also made to allocate certain proportions of the British output of 3-in. Stokes mortars towards the equipment of the Russian, French, Italian and American armies.[4]

(b) ECONOMY IN MONEY AND MATERIAL.

While output was thus being maintained, considerable economy was effected by an all round reduction of prices. This was largely facilitated by the existence of stocks which rendered the Department less dependent upon individual firms, and by administrative reorganisations which led to rapidity of payment.[5] Moreover, now that the initial stages of manufacture were past, it was possible to estimate more accurately the costs of production, and to avoid payments on a cost plus percentage basis. Negotiations with contractors were also rendered easier by a certain reduction in the numerous changes in design, which had been a cause of serious discontent, particularly among makers of the 3-in. Stokes bombs. Between January and October, 1916, the price of 3-in. Stokes bombs was reduced from 14s. to 7s. 9d. each, the price of 2-in. bomb-heads from 10s. to 8s. 6d. each.[6] The elimination of the costly 1·57-in. mortar, and the displacement of the complex artillery fuses by cheap and simple types specially adapted for trench mortar ammunition, had tended in the same direction.

The production of trench mortars and their ammunition, in common with that of all other stores, was considerably affected by restricted supplies of material from the beginning of 1917 onwards; but the limited utilisation of high-class steel in the manufacture of bombs gave this form of projectile an appreciable advantage over gun ammunition in this respect. The main change made to meet the

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1 (Printed) *Weekly Report*, No. 59, VII. (16/9/16).
2 *Ibid.*, No. 71, VII. (9/12/16).
3 HIST. REC./H/1610/11.
4 D.M.R.S. 262, B. 3.
5 C.R./T.W.D./1116 (3).
6 *Ibid.*

new conditions of the submarine campaign was the substitution of 80/20 amatol for ammonal as a bursting charge for trench mortar bombs. This alteration was effected early in 1917, as the result of experiments carried out by officers of the Explosives and Trench Warfare Supply departments in the previous summer.[1]

(c) SUBSTITUTION OF THE 6-IN. FOR THE 2-IN. MORTAR.[2]

Although the 2-in. mortar had been accounted the most efficient of the types evolved in the early days of trench warfare, and fired a bomb containing a large proportion (12 lb.) of high explosive, it had certain serious defects. During the spring of 1916 the "Temple" patent silencing device had been developed and issued with a certain percentage of the ammunition, to quench the flash and muffle the report from this mortar. The silencer was a species of heavy self-centring chuck screwed to the end of the barrel and used with a bomb having a special form of tail to which a piston with a gas check was attached. Upon firing, the bomb with the main part of the tail was projected forward; but the piston was held by the chuck, thus sealing the end of the barrel. The device was, however, only partially effective, since the consequent heating of the barrel prohibited its employment in prolonged bombardments, restricting its use to the night-time.[3] Thus, by day the mortar retained its chief original defect. Its limited range of between 500 and 600 yards contributed to the ease with which the enemy located it. Its rate of fire was very low, viz., about two or three rounds a minute, being dependent upon the several separate operations of inserting the charge, ramming it home and inserting the bomb. The weight of the mortar restricted its mobility. In the opinion of certain experts the spherical contour of the bomb seriously limited its effectiveness. The stick, which formed a considerable part of the weight, was invariably propelled backwards, often causing casualties in the British lines.[4] During the battle of the Somme, the 2-in. with the Newton fuse proved an effective means of wire-cutting, particularly when used in conjunction with 18-pdr. shrapnel; at the same time it caused alarm by throwing a considerable number of short rounds during rainy weather.[5]

In the autumn of 1916 a definite endeavour was therefore made to introduce an improved type of medium mortar. On 21 October instructions were given for trials of a 6-in. mortar, the design of which had been developed in France by Lt.-Col. H. Newton, who had cast experimental weapons from brass salved from empty S.A.A. cases. A Belgian design, the Van Deuren mortar, was considered at the same time; but its adoption was definitely rejected in January, 1917, upon

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[1] HIST. REC./H/1600/9, pp. 34-36.

[2] Based, where no other reference is given, upon Lt.-Col. H. Newton's account of the 6-in. mortar in HIST. REC./H/1600/14.

[3] HIST. REC./H/1610/11.

[4] *Ibid.*

[5] C.R./T.W.D./1120 (5).

the ground that the special steel and plant required for its production would give rise to prohibitive delays.[1]

Accordingly it was arranged towards the end of January, 1917, to produce 1,700 6-in. trench howitzers in order to replace the same number of 2-in. mortars.[2] Supply conditions had already been considered by Colonel Newton in developing the design. Arrangements were made to utilise rejected small arms cartridges as igniters. The difficulties experienced in obtaining suitable tubing for the stem of a stick bomb, as well as the danger inherent in the stick, was avoided by the use of a large-bore weapon firing a cylindrical cast-iron bomb with steel tails. After some delay in the settlement of priority between these weapons and certain naval supplies, tubes for the first 1,200 barrels were obtained from a single firm, and an order for their completion placed with another.[3] Delivery of the mortars began in the middle of the second quarter of 1917 and soon outpaced deliveries of ammunition, filling of which began to replace that of the 2-in. bombs at Erith towards the end of May. Overseas deliveries of ammunition began in June, 1917 ; and by the following May output had reached 32,000 weekly.

The new medium mortar improved upon the 2-in. mortar in many respects. Its original range of 1,000 yards was increased to 1,950 yards before bulk supply began. Its rate of fire was brought up to eight rounds per minute by the adoption of the Stokes mortar method of muzzle loading. Use of the comparatively costly and heavy steel cartridge container of the Stokes bomb was, however, avoided by introducing a striker-clip used in conjunction with the igniter and similar to that already adopted for the 4-in. Stokes smoke bomb.[4] The dangers of the flying stick were avoided. A special plug was provided, enabling a missfire round to be safely ejected by the insertion of a slow burning time-fuse attached to a powder bag.

(*d*) Improvements in Design.

No British heavy mortars, other than those based upon the French 240-mm. pattern, were adopted for service use throughout the war. Improvements were, however, made in the original 9·45-in. Mark I mortar. The pattern supplied to the Russian Government (Mark II) had a long barrel to increase range and a large chamber. In October, 1916, the Ordnance Committee began to investigate the French type with lengthened barrel and also various other designs of heavy mortars, including the Sutton-Armstrong mortar described above, and patterns produced by Vickers and the Royal Gun Factory.[5] The patterns evolved by the armament firms were in reality miniature heavy howitzers firing shell of artillery type fitted with copper driving bands. Their manufacture would have encroached upon the plant and labour needed

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[1] D.M.R.S. 262 C.

[2] *Ibid.*

[3] (Printed) *Weekly Report*, No. 77, VI. (27/1/17) ; No. 78, VI. (3/2/17).

[4] See below, p. 93.

[5] (Printed) *Weekly Report*, No. 67, VII. (11/11/16).

for producing and repairing artillery. It was therefore decided to meet additional requirements with Mark III of the 9·45-in. mortar, a modification having a long barrel and a small chamber.[1] Manufacture of 100 of these was accordingly put in hand in February, 1917.[2]

The early difficulties with 9·45-in. ammunition were obviated partly by increasing the cordite charge, partly by introducing a bomb with longer tail and with the front part of the vanes cut away, the rear corners of the vanes being twisted to give the projectile some rotation.[3] The use of inferior metal for the vanes produced inaccuracy; the inferior quality of the old type of bomb led to large numbers of prematures. The standard of metal used was therefore raised. The newer type of bomb (Mark IV) had only been issued in a small experimental lot at the conclusion of hostilities.[4]

During the whole of 1916 the ammunition of the 3-in. Stokes mortar gave very unsatisfactory results. Numerous prematures which occurred in the first half of the year were attributed to the "red" cartridge. This was the one of the three grades of cartridge which was used to obtain the maximum range of 430 yd. Its defects were ascribed by the supply department to early issues of unwaterproofed cartridges; but General Headquarters, France, stated in December, 1916, that the whole situation in respect to this ammunition was still unsatisfactory, every part of the round, viz., cartridges, bombs and pistol heads, being involved.[5] The following year brought a definite improvement in this position, particularly in regard to the propellant charge. Investigation showed that the "red" cartridge developed abnormally high gas pressures within the container, and that in consequence the container was shattered by the explosion of the cartridge. Accordingly an improved design of cartridge with a slower burning charge was adopted, and this defect was at once removed. Subsequently, in March, 1917, the introduction of a series of ring charges not only ensured safety, but also increased the range of the mortar up to a maximum of 825 yd.[6] The charge then consisted of a 12-bore cartridge filled with suitable ballistite and a priming charge of gun-cotton yarn. Various ranges were obtained by slipping over the container one to four cambric rings, each of which carried 110 grains Mark I cordite in flakes. Subsequent research produced a ring charge of E.C. 3 sporting powder within an envelope of celluloid. These rings had the great advantage of giving no muzzle flash. The main drawback to the use of ring charges was inaccuracy due to difficulty in protecting the charge from moisture. The introduction of winged cast-iron bombs similar to those for the 6-in. mortar also gave inaccurate results towards the end of 1917. In the meantime French authorities had been experimenting with the mortar, in their efforts to produce a satisfactory *canon d'accompagnement.*[7] Determining

[1] HIST. REC./H/1600/14, Chap. II., pp. 25-26.
[2] (Printed) *Weekly Report*, No. 78, VI. (3/2/17).
[3] HIST. REC./H/1600/14, Chap. II., p. 22.
[4] *Ibid.*
[5] D.M.R.S. 262, B. 3.
[6] *Ibid.*
[7] *Ibid.*

to design a better form of ammunition, they produced the Brandt-Maurice type of stream-line bomb incorporating the ring charge and giving a range of 2,500 yd. This form of bomb, together with a French direct action fuse, was approved for British service use; but it had not actually been brought into supply when hostilities ceased, nor had a charge which would ensure accuracy been determined.[1]

The second important problem in the design of the 3-in. ammunition was the development of a more satisfactory fuse, the central-fire time fuse, which was, however, the only reliable type actually used during the war. An "Allways" fuse (No. 146) with a spring and tape safety device was evolved to enable the bomb to function in whatever position it fell, and came into supply during the spring of 1917.[2] In its first form it proved unsatisfactory in many respects and was found dangerous to handle. Its improvement was under consideration throughout the period of hostilities, its latest form (No. 148) being fitted with the "Umney" safety shutter in place of the spring and tape device. Another "Allways" fuse (No. 147) which gave satisfactory results during trial had not yet been introduced into service at the date of the Armistice.[3]

Very great progress was made in regard to the range of all British mortars. In the autumn of 1916, General Headquarters, France, desired that the range of the 3-in. Stokes mortar should be increased if possible up to 600 yd.[4] The principle of the composite charge, as introduced in the rings for the 3-in. Stokes mortar, was established about this date as the result of experiments carried out by the Technical Adviser to Trench Warfare Supply department (Lieut. E. Goodwin) with the 9·45-in., and simultaneously by Major H. Newton with the 3-in. Stokes in France.[5] The use of a primary charge to give initial impulse to the bomb and ignite a secondary charge, which would act when the energy of the first was exhausted, doubled the range of the 3-in. and 4-in. Stokes mortars and of the 6-in. Newton.[6] Eventually the range of the new medium mortar was brought up to 2,000 yd.,[7] and when hostilities ceased experiments were in hand to obtain a still longer range by the use of correctly stream-lined bombs.[8]

(e) The Effects of Open Warfare.

The German offensive launched on 21 March, 1918, put a definite end to the siege warfare, which had given urgency and importance to the provision of trench ordnance since October, 1914. The conditions of supply had by this date been established so satisfactorily that the

[1] Hist. Rec./H/1600/14, Chap. II.
[2] D.M.R.S. 262, B. 3.
[3] Hist. Rec./H/1600/14, Chap. II., p. 12.
[4] D.M.R.S. 262.
[5] C.R./T.W.D./1121, f. 261; Hist. Rec./H/1600/14.
[6] C.R./T.W.D./1121, f. 261.
[7] Hist. Rec./H/1610/14, Chap. II., p. 16.
[8] *Ibid.*, p. 18.

large losses of the retreat were speedily replaced. During the first fortnight of the Allied retirement over 1,200 mortars were despatched overseas together with 170,000 rounds of ammunition to re-equip the British forces, and also to supplement supplies for the French army.[1] Early in May normal deliveries were resumed, issues maintained at the usual rate, and stocks built up, until towards the end of June notification was received that the supplies of trench mortar ammunition in France were sufficient to meet the whole of the year's requirement and that no further output would be needed.[2]

Some modifications were introduced in the patterns of existing mortars to meet the new conditions of open warfare. In addition to the increases in range which have been described above, investigations were closely concerned with the re-designing of mountings and other methods of improving mobility. Thus an extremely light and portable equipment was introduced for the 3-in. Stokes mortar. This dispensed with the elevating stand, retaining only the mortar and its base-plate, the mortar being held by handles attached to the barrel and a sling across the body of the gun-layer.[3] Numerous mobile mountings were improvised in France for the 6-in. trench howitzer, and a wheeled carriage with ammunition limber was designed by the Trench Warfare department to carry the mortar on its mounting, so that it could be readily brought into action by merely removing the wheels of the carriage.[4] Even the heavy 9·45-in. mortar was rendered more mobile by the introduction of horse-carriages of French design in place of the original hand-trucks, although the weight of the sub-bed still involved lorry transport for this part of the equipment.[5]

VII. Summary.

Since ammunition has always been a limiting factor in the supply of trench ordnance, some idea of the total achievements attained in producing these stores can best be gathered from the total numbers of the three chief classes of bombs supplied under the Ministry of Munitions. Over eleven and a half millions of standard light mortar ammunition (3-in. Stokes) was produced at varying rates which reached a maximum of 95,000 weekly. About three and three-quarter millions of medium bombs (2-in. and 6-in.) were produced in all. The total supply of heavy bombs was between a quarter and half a million. These figures exclude the emergency types of ammunition issued during the first 15 months of trench warfare.

Mere numbers, however, denote but a slight part of the deeds accomplished. In October, 1914, the British Army possessed not a single trench mortar, not a round of mortar ammunition; neither were there in the country firms experienced in making these weapons

[1] (Printed) *Weekly Report*, No. 136, XI. (6/4/18).

[2] *Ibid.*, No. 148, VI. (A) (29/6/18).

[3] HIST. REC./H/1600/14, Chap. II., p. 9.

[4] *Ibid.*, p. 17.

[5] *Ibid.*, p. 21.

nor a pattern to which they could be made. During the first nine months of siege warfare several more or less efficient types were evolved, and about 300 mortars were issued to the troops who also occupied themselves in improvising others. Supply at this time was strictly limited by the amount of ammunition available. This was designed to use existing components which were immediately available in small numbers, but could only be produced in large quantities at the expense of the more highly valued ammunition for artillery.

In the summer of 1915 Mr. Lloyd George, in organising the production of every class of munition in unprecedented quantities to meet the needs of the growing armies, insisted personally upon the production of those types of mortar which could be made most readily. So a new light mortar, the 3-in. Stokes, was manufactured by the thousand, and production of the most efficient of the medium mortars, the 2-in., was organised on the same scale among commercial firms, without encroachment on the country's already over-taxed capacity for artillery. A few months later the Minister also borrowed from the French Government a sample heavy mortar, arranging for its reproduction in considerable numbers.

The supply of ammunition was organised simultaneously from sources hitherto untouched. Extraordinary efforts to provide immediate supplies for the Loos offensive and for the army in the Dardanelles bore comparatively little fruit and tended to delay the steadier preparations for the 1916 campaign. The issue of emergency types of smoke ammunition for the Battle of Loos was the most noteworthy result of these special activities. The restriction in the use of the few mortars then existing by the paucity in the supply of ammunition is well illustrated by the report on munitions in the field on the eve of that battle. There were in France, on 11 September, 1915, 291 3·7-in. mortars with enough ammunition for 180 rounds apiece. The ammunition for the remaining types was so little as to be insignificant. There was one round apiece for the 40 4-in. and 37 2-in. mortars in the field; there were nine rounds each for 137 1·57-in. mortars. By the end of 1915 the limited supplies from the original armament makers, particularly the Ordnance Factory, were only beginning to be outpassed by deliveries from the new commercial sources. Output of ammunition was still held up by the conditions of its design, in particular by the complex nature of the artillery fuses which had been adopted in the first instance. Bombs were filled in large numbers, but no issues could be made until corresponding quantities of fuses were available.

This defect, which existed in every one of the original types of bomb, was immediately remedied when the supply authority took over responsibility for design. By February, 1916, the use was sanctioned of fuses which were simple to make and specially fitted to the conditions of trench mortar ammunition. The issue of complete rounds in large numbers began within a few weeks of this approval. By May, 1916, the Army in France held, in addition to considerable numbers of the less efficient types, 568 of the standard medium mortar with

437 rounds apiece, 621 of the new light mortar with 1,003 rounds apiece, and 12 heavy mortars, obtained from the French Government, with 235 rounds apiece. Accordingly, the Commander-in-Chief in France considered himself so well equipped with trench warfare *matériel* that the question of *personnel* could regain its prior place, and the various less efficient types of trench mortar were discarded at considerable financial loss, in order to facilitate the use of the three kinds retained—the Stokes mortar as a light weapon, the 2-in. as a medium, and the 9·45-in. as a heavy, mortar. In October, 1915, the equipment of the British Army with trench mortar batteries had begun on a divisional basis. The supplies, which had been fully organised by the spring of 1916, were maintained to meet the varying programmes throughout the war. With the resumption of open warfare in the spring of 1918, and the building up of stocks when once the losses of the German advance had been met, the need for trench weapons diminished. Accordingly in June, 1918, output was stopped, since the ammunition already held was considered sufficient for the whole year.

Important developments in the design of the mortars used took place after the three types had been fixed in May, 1916. A new and more efficient pattern of medium mortar, the 6-in., was substituted for the 2-in., which it replaced gradually during 1917 and 1918. The defects of the 3-in. Stokes mortar were in part remedied, but the development of an ideal fuse, the most important problem in the design, was only partially solved at the cessation of hostilities. The chief general advance made was a very notable increase in the range of all mortars. When the war ceased these weapons were being adapted to the conditions of open warfare, and several important problems in their design appeared to be upon the verge of solution. The British service was provided with patterns which were safe and efficient. One of these, the 3-in. Stokes mortar, had been adopted generally as a standard weapon by the Allies. This daring invention had features which at first appeared obviously impracticable in the eyes of experts, but it eventually proved one of the great successes of the war.

CHAPTER IV.

GRENADES.[1]

I. Introductory.

Grenades are divided into two important classes according as detonation is secured by means of a percussion or a time fuse. Again, they are classified as hand or rifle grenades, according to the means of propulsion used.

The spherical grenade, which played an important part in the battles of the 16th, 17th, and 18th centuries, was entirely obsolete at the outbreak of war in 1914, and no stocks existed.[2] The experience of the Russo-Japanese War had led to the introduction of a single British Service type of percussion grenade (No. 1, R.L.), which was produced by the Ordnance Factories in extremely small quantities, and was neither perfectly efficient nor entirely safe. There existed in August, 1914, certain patent grenades, the invention of Mr. Marten Hale and the monopoly of a single firm, the Cotton Powder Company. One form of the Hale rifle grenade had for some months been under the consideration of the Ordnance Board as armament for aircraft.[3] The Hale Mexican hand grenade (No. 2), made for delivery to Mexico to quell street rioting, existed in small quantities, which were soon exhausted.[4]

The enemy was superior both in trained bombers and in efficient types of grenade.[5] The only British soldiers trained in their use were the Royal Engineers.[6] Soon after the inception of trench warfare it became necessary to train a certain proportion of the infantry as bombers[7]; but this was not seriously undertaken until May, 1915.[8] The establishment about May, 1915,[9] of the Clapham School for bombing instructors, under Major C. E. W. Beddoes, and the subsequent organisation of bombing schools in each Home Command,

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[1] Based, as regards questions of design, upon a statement on grenades drawn up by Major C. E. W. Beddoes, O.B.E., of the Gloucestershire Regiment (Hist. Rec./H/1600/14, Chap. III.).

[2] *Ordnance Board Minutes* 12003 (ii).

[3] *Ibid.*, 9426, 9536.

[4] Hist. Rec./H/1600/14, III. 38.

[5] 121/Stores/970.

[6] C.R./T.W.D./1117.

[7] 121/Stores/970.

[8] Hist. Rec./H/1600/14, III. 38; Sir J. French to W.O., 20/5/15, cited in 121/Stores/2827.

[9] Hist. Rec./R/1600/20.

under Major Beddoes' inspection, greatly facilitated the equipment of the Army with those types of grenade of which some experience was particularly necessary as a safeguard against accident. In these schools nearly 12 million Mills grenades alone were expended with only ten fatal accidents.

II. The Position of Supply, 1914-15.

(a) GROWTH IN THE DEMAND.

Certain comparatively small quantities of Hale rifle grenades were purchased from the Cotton Powder Company between August and October, 1914.[1] During November and December these orders were increased, and in November efforts were made to obtain regular weekly deliveries of Mexican hand grenades, about 13,600 of which were ordered during the third week of November.[2] The average numbers issued to France weekly during November were 630 rifle and 70 hand grenades.[3] These included the output of the Ordnance Factory. On 5 December, 1914, the Commander-in-Chief notified that the minimum weekly supply so long as trench warfare lasted should be 2,000 rifle and 4,000 hand grenades. He stated that a much simpler and cheaper pattern than the Service hand grenade would suffice.[4] A fortnight later he wrote that a liberal supply of hand grenades was essential. There had recently been occasions when his troops had been forced out of captured trenches by their inability to reply effectively to the enemy's bombers.[5] By this date supply had advanced a little upon the November position, and in the week ending 15 December, 1914, issues had been made of 1,600 rifle and 2,500 hand grenades. Deliveries had not, however, reached the full requirement when the demand was raised to 10,000 hand grenades weekly in the first week of 1915, and to 5,000 rifle grenades weekly in the following March.[6]

The use of grenades increased very rapidly during the spring offensive. The capture of the enemy's first and second lines was generally followed by severe fighting for a third line and the attack of narrow communication trenches by bombing parties. In these actions large quantities of grenades were expended. Decision was taken to train all infantrymen as bombers, and in June, 1915, the total demand for hand and rifle grenades for France alone was accordingly raised from 15,000 to 42,000 weekly on the basis of the daily expenditure of 2,000 of each class.[7] Moreover, it was anticipated in July, 1915, that the total requirement would possibly reach 700,000 grenades weekly when the new British armies took the field.[8] A more urgent and immediate need for equipping the Mediterranean forces with

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[1] 94/G/5.

[2] Contracts/G/1904 ; Contracts/G/1929.

[3] 121/Stores/984.

[4] *Ibid.*

[5] 75/3/2486.

[6] 121/Stores/984.

[7] 121/Stores/2827.

[8] Col. Bird (S.D. 2) to A. 3 (*ibid.*).

grenades arose in this month. Issue of 10,000 grenades weekly was requested by Sir Ian Hamilton on 7 July, as his troops in the Dardanelles were " at a disadvantage both physically and morally " by reason of their deficiencies in this respect in the face of an enemy with an unlimited supply.[1] The demand did not cease to grow. In August, 1915, the Commander-in-Chief, France, notified that the requirements formulated in June had been considerably under-estimated. For a force of 48 divisions he would need 294,000 grenades weekly, on the basis of a daily expenditure of 16,000 rifle, 9,000 percussion, and 17,000 time grenades.[2] This demand was again revised in the following November.[3]

(*b*) LIMITING FACTORS IN THE SUPPLY.

Output of the R.L. percussion grenade and the Hale grenade was strictly limited by their special detonators, which were designed to ensure safety but were incapable of rapid manufacture on existing plant. There were only two British firms which had the special plant and labour needed for detonator production. In normal times these two companies supplied 80 per cent. of the detonators used in England for commercial purposes, the remainder being of German or Belgian manufacture. These firms also supplied world-wide requirements of the mining industries.[4] Moreover, the same unit of plant would produce only 5,000 of the special detonators as against 50,000 or 90,000 of the two more common types.[5]

The attitude of the monopolist grenade makers also tended to hamper supply. Their deliveries were in arrears and their prices high.[6] Great difficulty was experienced in getting from the company the particulars which were essential in order to spread the sources of supply by establishing other contractors for rifle grenades.[7] The firm itself met with considerable difficulties in the supply of machine tools and plant for expanding manufacture and in finding efficient sub-contractors.[8]

III. Attempts to Increase the Production of Service Percussion and Rifle Grenades, December, 1914—June, 1915.

Under these circumstances, the department concerned (A.3) tried early in December, 1914, to increase supplies by finding other firms to make and fill grenades of the Hale pattern (rifle and Mexican). The drawings necessary to enable tenders to be invited were not, however, completed until the first week of March, owing to difficulty

[1] Sir Ian Hamilton to W.O., 7/7/15 (*ibid.*).

[2] C.R./T.W.D./1115 (3).

[3] See below, p. 80.

[4] T.W. 2050.

[5] 121/Stores/3439.

[6] 94/G/5.

[7] 75/3/2485.

[8] 94/G/5.

experienced in getting the necessary information from the company.[1] Tenders were finally issued on 31 March, 1915, with a view to meeting the increased demand for rifle grenades,[2] the most promising of the new sources of supply being the firm of Roburite & Ammonal.[3] In the meantime the Cotton Powder Company had been pressed to reduce its prices and above all to expedite its output; for, although orders had been placed to meet the whole requirement, promises of delivery were not kept.[4] Early in March the company revised all its grenade prices, naval and military, and reorganised its grenade department. Simultaneously, Mr. Marten Hale transferred his services to Roburite & Ammonal, and the purpose of the department in introducing a new contractor was thus defeated, the attitude of the two firms remaining "inexplicably unsatisfactory."[5] Both companies experienced practical difficulty in expanding capacity, the one in obtaining efficient sub-contractors for grenade bodies or in producing more than a limited number (15,000 weekly) of the special detonators, and the other in obtaining trade-made detonators.[6] The Cotton Powder Company attempted to solve the problems as to sub-contracting by subsidising a single capable firm which was already producing 10,000 grenade bodies weekly on special plant.

In April, 1915, direct orders for empty rifle grenade bodies were placed with this sub-contractor by the War Office; but no arrangements were made for filling or for the supply of the limiting factor in production, viz., the special detonator. Negotiations continued with Cotton Powder Company and Roburite & Ammonal and with a fourth firm, but arrangements for certain components, such as cartridges, boxes and tins, had not been completed when the Ministry of Munitions became responsible for supply at the end of June. The output from the existing contracts was then estimated at about 6,000 weekly during July, rising to 23,700 by 21 August, and decreasing after that date. The main difficulty was still the production of special detonators.[7]

Output[8] of the R.L. percussion grenade advanced slowly for the same reason. Down to the end of 1914 issue had been made of rather more than 2,000. During the first quarter of 1915 the Ordnance Factory produced about 23,600 percussion grenades and a few hundred time-fused grenades. Attempts were being made to increase accuracy and safety by the addition of streamers to make the grenade fall on its head, and by shortening the handle, which was dangerous to the thrower. An experimental lot of the modified percussion grenade was sent to France towards the end of December,[9] and production of the R.L. percussion grenade in its second mark began in the second quarter of 1915. In that quarter about 14,800 percussion grenades were

[1] 75/3/2485.

[2] *Ibid.*; 121/Stores/984.

[3] 94/G/20.

[4] 94/G/5.

[5] 121/Stores/2827; T.W. 663.

[6] 121/Stores/3439.

[7] C.R./T.W.D./1115 (1).

[8] For figures of output, see Appendix XI.

[9] 75/3/2486.

issued in addition to some 27,000 time-fused grenades. On 20 May, 1915, General Headquarters, France, named the modified form of R.L. grenade as the standard percussion grenade.[1] Early in June, attempts were made to spread the sources of supply by placing contracts for the grenade bodies with three firms; but the Ordnance Factory remained the sole maker and filler of the detonator.[2]

IV. Production of Time-fused Emergency Grenades, 1914-15.

(*a*) LOCAL MANUFACTURE.

While output at home was still hampered by the conditions described above, the troops in the field were driven to improvise their own grenades[3] from whatever materials were immediately available. Most of these improvised missiles consisted of a canister, often a jam tin, filled with the engineering explosive at hand, *e.g.*, ammonal or gun-cotton, and fired by a short length of another engineering store, viz., Bickford time fuse. The fuse had to be lighted before the grenade was thrown, and many accidents occurred, their number being inevitably increased by lack of training among the troops. The use of these extemporised weapons marks the introduction of time-fused grenades, which eventually entirely superseded percussion grenades.[4]

The troops on the Western and Mediterranean Fronts drew from stores on intermediate demands many of the components for making their own grenades. Eventually this system led to considerable competition between the army workshops and supply authorities at home in respect to articles, such as detonators, which were difficult to manufacture. Accordingly, in December, 1915, when home supplies had been built up, the War Office put a stop to local manufacture of hand grenades, except for the completion of existing contracts; but local production of rifle grenades continued, as the supply of those was still limited. The troops still filled those hand grenades which they had already made themselves.[5]

(*b*) EMERGENCY MANUFACTURE AT HOME.

During the first half of 1915, systematic efforts were made by Colonel Jackson's section to produce at home large quantities of simply made grenades similar to those which the troops were improvising. Sir John French had informed the War Office on 5 December, 1915, that a much cheaper and simpler pattern than the R.L. percussion grenade would meet his needs.[6] He was ready to accept any pattern of hand grenade which could be produced immediately.[7] A proposal

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[1] 121/Stores/2827.
[2] C.R./T.W.D./1115 (1).
[3] Cf. Sir J. French to W.O., 5/12/14 (121/Stores/984).
[4] For a list of the chief grenades introduced, see Appendix XIII.
[5] 121/Stores/3603.
[6] 121/Stores/984.
[7] *Ibid.*

was made to copy the French spherical grenade, which needed comparatively little skill in throwing, though the pattern was considered most dangerous by British authorities. The scheme was eventually abandoned on the ground that special plant would be needed.[1] The Chief Superintendent of Ordnance Factories was consulted as to the means of making a cheap pattern which should be capable of speedy manufacture without too great a loss of efficiency, and proposed certain alternatives, *e.g.*, to use high explosive in a tinned cast-iron casing. He was, however, hampered in producing a design by lack of an authoritative decision as to the most suitable all-round type.[2]

In the meantime Colonel Jackson's section was reduplicating in quantity the Jam-pot and Hair-brush grenades made by the troops and sending out Double-cylinder grenades.[3] In many of these emergency patterns the factor of safety was increased by substituting a friction igniting apparatus for the portfire and Bickford fuse formerly used.[4] In April, 1915, orders for loaded Pitcher grenades were placed with two explosive firms.[5] These grenades were of two weights (Nos. 13 and 14), and were issued in several tens of thousands. They were fired by means of a friction igniter, but accidents with them were so numerous that they won for the bombers the name of "The Suicide Club."[6] They were followed by Ball and Oval grenades, which resembled each other in design but not in shape. These consisted of a cast-iron body, into which was screwed a plug with a sleeve to take the detonator, which was fired in the first place by Bickford fuse and a portfire, and later by a friction igniter. Supply of the Ball grenade (No. 15) began in July, 1915, and output reached 200,000 weekly by the end of August, 500,000 weekly by the middle of November. Output of the Oval grenade began in October, 1915, and reached 300,000 weekly in January, 1916.[7] Large quantities of the Ball grenade, in its earlier form, were issued to France for the Battle of Loos, but they failed completely owing to wet weather, for which the first method of ignition was unsuitable. The troops lost confidence in this pattern, although the subsequent friction igniter was safer and more efficient, being adequately protected from the damp. In consequence, about a million grenades were withdrawn from service, the only use authorised being as ammunition for catapults.[8] Several millions of Ball and Oval grenades were sent to various Allies, particularly to Russia; but issue of these and other emergency types to British forces ceased at the end of 1915, when the supply of a safe and efficient time-fused grenade had been fully organised.[9] In the case of direct orders placed for the Ball

[1] 75/3/2486.
[2] *Ibid.*; cf. 75/7/9446.
[3] HIST. REC./H/1600/8.
[4] *Ibid.*, 1600/14, p. 41.
[5] 94/G/164.
[6] HIST. REC./H/1600/14, III., p. 38; *ibid.*, 1640/1, p. 41
[7] *Ibid.*, 1640/1, p. 41.
[8] D.M.R.S. 262 A.
[9] *Ibid.*

grenades, the contract terms enabled production to be closed down immediately; but large numbers of deliveries were accepted on orders which had been placed through certain local munitions committees.[1]

V. Development of a Satisfactory Time-fused Grenade.

The new type of time-fused grenade (the Mills, No. 5) was introduced as a hand grenade, and adapted some time later for use with a rifle. It had a cast-iron barrel-shaped body, fitted with an aluminium tube or centre-piece, communicating with a cylindrical chamber, for the detonator. A 5-sec. fuse, inserted in the central tube, was attached to the detonator, and ended in a rimfire percussion cap. The cap was fired by means of a steel plunger or striker, held back by an external lever which was secured by a safety pin.[2] The general idea was of Belgian origin. It was developed and patented by Mr. William Mills, of Birmingham.[3] The pattern was submitted about January, 1915,[4] and experimental work was completed by 21 April, when tenders were invited for 150,000.[5] On 20 May, 1915, Sir John French, in formulating his general requirements for grenades,[6] gave preference to No. 5 over the R.L. time-fused grenade, with friction igniter, which had recently been manufactured in some thousands, and was issued in two sizes, weighing respectively one and two pounds.[7] By the beginning of July between 27,000 and 28,000 of the R.L. time-fused grenade had been issued[8]; and production of the Mills grenade was beginning to be established, 16,000 in all having been delivered.[9]

The production of the Mills grenade-body was comparatively simple, and output had been organised on five contracts by the beginning of July, 1915.[10] A scheme for subdividing the various operations in manufacture and filling was under organisation when the Minister of Munitions became responsible for the supply. Orders had been placed for certain parts, chiefly the body; but delays had been experienced in the actual subdivision of the working drawings owing to the pressure of work on the limited inspection staff, and an attempt to persuade the better-known firework makers to undertake the filling of these grenades had been unsuccessful.[11] During July and August 1915, the filling of grenades by contractors was systematically organised

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[1] C.R./T.W.D./1115 (3); Hist. Rec./H/1640/1, p. 44.
[2] Hist. Rec./H/1600/14, III., p. 43.
[3] *Ibid.*, p. 42.
[4] Hist. Rec./H/1600/8.
[5] 94/G/125.
[6] 121/Stores/2827.
[7] Hist. Rec./H/1122. 1/1; *ibid.*, R/1122. 11/16.
[8] *Ibid.*
[9] Hist. Rec./H/1640/1.
[10] 94/G/125; Hist. Rec./H/1640/1.
[11] 121/Stores/2827.

on an immensely increased scale. The process was comparatively, simple and little capital outlay was involved. It was taken up chiefly by the smaller fireworks makers, particularly the Yorkshire firms, whose business had been brought to a standstill by the official embargo on firework displays. A building contractor, Mr. W. E. Blake, formed a new company, the Blake Explosives Loading Company, for this purpose, establishing next to the works, where he made grenade bodies at Fulham, a filling factory, which was afterwards converted into a national bomb-filling factory.[1] The provision of detonator sets was a limiting factor in producing Mills grenades until the end of September, 1915; but the initial difficulties of production were overcome by the following month, and by January, 1916, the output of this type had reached 800,000 weekly.[2]

VI. Reduction in Types.

In the first urgency of the winter of 1914-15 the forces in France were ready to accept any kind of grenade which could be readily produced, although the issue of miscellaneous types added to the difficulty of formulating a demand.[3] The increased use of grenades by inexpert bombers during the spring of 1915 made a reduction in the number of types extremely desirable. On 20 May, Sir John French asked that future manufacture should be limited, so far as possible, to one class of rifle grenade, the Hale (No. 3), one of percussion grenade, preferably R.L. No. 1, and one of time-fused grenade, viz., the Mills.[4] Shortly afterwards he urged that standardisation should take place as soon as possible, since instances had recently occurred of the issue of one type to men trained only in the use of another. At the same time, issue should not be limited to the standard patterns until an adequate supply had been built up. Urgent demands for increasing numbers were then (June, 1915) being received from Army Commanders. Until a plentiful supply of the types preferred was forthcoming, hand grenades of any type available should be sent out in as large quantities as possible.[5]

(a) Elimination of the Emergency Types, November, 1915.

It was to meet these general demands that stopgaps, such as the Ball grenade, were issued for the Battle of Loos. The unfortunate experiences with this type during the autumn emphasised the need for standardising efficient patterns. Accordingly, on 8 November, 1915, it was asked that all time-fused grenades except the Mills should be withdrawn from service. Production of the two other standard patterns was still strictly limited by the difficult nature of the design. New patterns were, however, under consideration. Until these should be perfected the Hale rifle grenade and the R.L., or alternatively

[1] Appendix VII.
[2] Hist. Rec./H/1640/1, p. 15.
[3] 121/Stores/984.
[4] Cited in 121/Stores/2827.
[5] Sir J. French, 21/6/15 (121/Stores/2827).

the Mexican, percussion grenade would be accepted. The requirement for all British armies between November, 1915, and May, 1916, was fixed at weekly rates rising from 395,000 to 457,300 in the case of the Mills grenade, and varying between 58,000 and 64,700 for the percussion and between 101,000 and 114,400 for the rifle grenade. No difficulty existed in maintaining production of the Mills grenade to meet this demand; but the nature of the special detonator still limited the maximum output of the percussion grenades to 55,000 weekly, and the complex design of the rifle grenade restricted the estimated production to 70,000 weekly.[1]

(b) ABANDONMENT OF PERCUSSION HAND GRENADES, MAY, 1916.

Percussion grenades have considerable practical advantages over time-fused grenades, but the satisfaction of safety conditions is a problem more easily solved in the latter. In particular, the service percussion types were unsuitable for close work, and lacked the essential factor of protection for the bomber if he dropped the grenade.[2] On the other hand, the popularity of the Mills time-fused grenade and the comparative ease with which it had been supplied in large numbers, eventually led to its adoption as the only type of hand grenade in May, 1915, and to the consequent abandonment of percussion grenades.[3] By this date, the steps taken to augment the supply of percussion grenades had brought up to requirement the combined output of the two original types (Nos. 1 and 2) and of a new and simpler pattern (No. 19), which had been evolved by the supply department and authorised for service use in January, 1916.[4] Contracts were cancelled upon the notification of change in the demand, but the only use found for about a million and a half of surplus grenades was to break them down into their component parts.[5]

VII. The Production and Development of Rifle Grenades.

(a) THE RIFLE GRENADE PROPER.

The Hale rifle grenade (No. 3, ·303 short rifle percussion grenade) was made of solid steel bar to a pattern requiring a great deal of machining. It had a brass base-piece also machined to allow a vane to be screwed home, the boss just covering two retaining bolts which held back the striker. A rod acted as a means of firing and also as a tail to steady the flight. On shock of discharge, a safety socket set back, freeing the vane to the unscrewing action of the wind, which released the bolts and upon impact allowed the striker to go forward on to the percussion cap of the detonator.[6]

The special design of this grenade remained a limiting factor in production throughout the year 1915. In addition to the difficulties

[1] D.M.R.S. 262 A.

[2] HIST. REC./H/1600/14, III. 40.

[3] *Ibid.*

[4] HIST. REC./H/1640/1, p. 20.

[5] D.M.R.S. 262 A.

[6] HIST. REC./H/1600/14, III., p. 50.

experienced in obtaining capacity for the detonator, the very high degree of accuracy needed seriously retarded output.[1] Indeed, the Cotton Powder Company, whose experience in the manufacture was unique, maintained that the design involved such accuracy that they could not guarantee less than 15 per cent. of rejections.[2] For some months the supply officers of the Trench Warfare department awaited the development of a simpler form of rifle grenade, for which several proposals were investigated without success. Eventually, after the receipt of the increased demand in November, 1915, steps were taken to increase the number of contractors by certain carefully chosen firms whose output during the following spring was estimated at 40,000 weekly.[3] With the 30,000 weekly already produced by the original firms, a delivery of 70,000 weekly was thus anticipated against the demand for over 100,000, which was again increased on 21 December.[4] Any considerable increase above the 70,000 would have involved the use of machines already occupied on other Government work of importance.[5] The capacity for detonators had been built up by December, 1915; by March, 1916, output of the No. 3 grenade had reached 80,000 weekly, when a new and simpler pattern was introduced.[6]

Experience gained in the manufacture and filling of No. 3 rifle grenade led to certain important modifications. A vaneless form (No. 20) came into supply early in March, 1916, when arrangements were made for most of the contractors to change over to this type.[7] The new pattern was cheaper than the old, obviated many of the manufacturing problems and was also more efficient. After its introduction the percentage of failures was considerably reduced; but prematures, which had been a serious cause of trouble with the original pattern, still continued. These were remedied by a modification (No. 24), which was introduced in the autumn of 1916, and overcame by the use of a waxed paper container dangers due to the exudation of the explosive.[8] Other minor modifications were made simultaneously with the purpose of cheapening manufacture, and the use of butt-welded iron and steel tube was sanctioned for the bodies in order to facilitate supply.[9] Mark II of this design was made in cast iron with a view to economy and efficiency, better fragmentation and penetration being obtained with this metal. Finally in the summer of 1917 manufacture began of a further modification, No. 35, having a detonator holder adapted for the service S.A. cartridge.[10] The main feature in this new design was economy in material, since the body

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1 HIST. REC./H/1600/14, III., p. 51.

2 D.M.R.S. 262 A.

3 C.R./T.W.D./1115 (3); HIST. REC./H/1640/1, p. 23.

4 (Printed) *Weekly Report*, No. 23, III. (1/1/16).

5 D.M.R.S. 262 A.

6 HIST. REC./H/1640/1, p. 23.

7 (Printed) *Weekly Report*, No. 33, III. (11/3/16).

8 HIST. REC./H/1600, 14, III., p. 52.

9 (Printed) *Weekly Report*, No. 55, VII. (19/8/16).

10 HIST. REC./H/1600/14, loc. cit.; (Printed) *Weekly Report*, No. 97, IX. (23/6/17).

was of cast iron and the brass parts were cut down to a minimum.[1] Production of this pattern was undertaken at the Royal Laboratory, where a weekly output of a million and a half had been reached by 22 September, 1917.[2]

Before these developments of the Hale rifle grenade had produced an article which could be cheaply and readily produced and was free from the defects of the original pattern, the army workshops had supplemented the meagre supplies of the Hale grenade with the Newton or Pippin rifle grenade. About three million of these were made in the 2nd Army workshops at Hazebruck. They were more efficient than the Hale grenade, which was then being issued in totally inadequate numbers; but they did not compare favourably with the later improved and cheapened designs of the service rifle grenade.[3] Although the supply of rifle grenades had substantially increased by the beginning of March, 1916, it still fell considerably below requirements. Accordingly, steps were taken to meet the balance of the demand by home production of the Pippin grenade. Preliminary orders were given for 500,000 of these, and trials of the first 300 were held with satisfactory results towards the end of April.[4] By this means, and by improvements in the supply of No. 3 and its modifications, the output was brought up to requirement towards the end of May, 1916,[5] but reports of prematures with the Pippin grenade were then received from France, and production of this pattern was suspended pending further investigation of the design.

(b) COMBINED HAND AND RIFLE GRENADES, 1916.

The design of rifle and hand grenades was developed along distinct lines until an adaptation of the Mills grenade for firing from the rifle was made in France. A pattern of Mills grenade modified for use with the rifle was approved as service design (No. 23, Mark I), and increased the range of the grenade by 50 yd. The aluminium base-plug of the Mills grenade (No. 5) was replaced in this pattern by one of steel, into which could be screwed a short steel rod, enabling the grenade to be projected by a 35-grain blank cartridge. A special appliance or rifle cup was designed to hold the lever in position and secure the striker until the rifle was discharged.[6] A formal requirement for initial issue of 720,000 of these rifle grenades, with a reserve of 280,000 and a weekly supply of 10,000 (afterwards raised to 20,000) for instructional purposes, was made on 5 May, 1916.[7] Orders were placed towards the end of the month, but the first deliveries came in slowly, until in July additional contracts were given for the steel base plugs, manufacture of which was

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[1] HIST. REC./R/1000/97.

[2] (Printed) *Weekly Report*, No. 110, IX. (22/9/17).

[3] HIST. REC./H/1600/14, III., pp. 53-54.

[4] D.M.R.S. 262 A; (Printed) *Weekly Report*, No. 39, VIII. (29/4/16).

[5] D.M.R.S. 262 A.

[6] HIST. REC./1600/14, III., 43.

[7] D.M.R.S. 262 A.

a limiting factor in output and cast-iron was sanctioned as an alternative to steel for this purpose.[1] Subsequently, in its second mark, grenade No. 23 was adopted for use either by hand or with a rifle. In this form it rapidly superseded No. 5, the Mills hand grenade,[2] supply of which ceased altogether in the autumn of 1917.[3]

VIII. Changes in Programme and Improvements in Design, 1916-18.

Thus by the autumn of 1916 the country's capacity for grenade manufacture had been effectively organised and the types employed considerably revised to ensure efficiency and convenience in the field and cheap and rapid production at home. The use of a time-fused hand grenade was universal; all forms of percussion hand grenade had been abandoned, although research in this direction still continued. Output had been much simplified by the adoption of a combined hand and rifle grenade, which was eventually to supersede entirely the time-fused hand grenade and to supplement to a large extent the original types of rifle grenade. Little subsequent change took place in the class of grenades used; but a good deal of experimental work combined with manufacturing experience produced important improvements in existing types. The organisation of supply was mainly characterised by very considerable fluctuations in the numbers required and produced.

(a) Later Changes in Type.

Throughout the war the Mills grenade in its various forms retained its position as the most important service grenade, in view of its well-known reputation as a serviceable weapon.[4] A few new types only were developed for particular purposes for which it was not suited. Thus the Egg time-fused grenade was introduced in 1917 to counteract the superiority attained by German bombers by the use of a light grenade. The Mills grenade weighed 24 oz.; the British Egg grenade (No. 34) only 12 oz.[5] Trial orders were placed for this lighter grenade in February, 1917.[6] The demand for bulk supply (500,000) was received towards the end of September. By the end of the year there had been built up an organisation of nine manufacturers producing between sixty and seventy thousand weekly,[7] and supply continued regularly until the termination of hostilities.

Again, on 28 April, 1918, shortly after the first employment of tanks by the enemy, the British army in France asked for 500,000 anti-tank grenades, to a pattern of short-range rifle grenade which had already been adapted in France from the No. 24 grenade, since

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1 (Printed) *Weekly Report*, No. 50, VII. (15/7/16).
2 Hist. Rec./H/1600/14, III. 45.
3 Appendix XIII.
4 Hist. Rec./H/1600/14, III. 48.
5 *Ibid.*
6 (Printed) *Weekly Report*, No. 78, VI. (3/2/17).
7 D.M.R.S. 262 H.

recent trials had proved that existing designs produced little or no effect against tanks. It was at first intended to supply immediate demands by local manufacture in France; but the pressure on the Army workshops during the spring campaign was so great that dependence had to be placed on home production.[1] By the end of the year 97,781 grenades (No. 44) had been delivered[2] and another design of superior bursting effect (No. 46) had been perfected. Another type was subsequently investigated for aircraft use. This was the No. 48, fired from a rifle by means of a discharger cup.[3]

(b) Special Grenades.[4]

All the types already described were grenades filled with a high explosive, usually some form of ammonium nitrate mixture. The use of special grenades expanded considerably during the last two years of the war. They had been issued in small quantities only during the year 1915. The emergency types then produced had consisted chiefly of tin containers filled with irritant or smoke-producing substances. The earliest of these were " stink " bombs evolved by Colonel Jackson of F.W. 3a, in conjunction with the Chemical Sub-Committee of the Royal Society, from December, 1914, onwards. Among the most important were glass bottles containing " SK," a lachrymatory liquid and inserted in a small canister to be thrown from catapults or by hand. After the German gas offensive of 24–25 April, 1915, the researches already carried out in this respect were applied in practice to the production of tin-containers for various irritant mixtures pending the slower development of cylinder-gas. The containers were hastily made and many leaked in transport. Westonite grenades, consisting of a glass bulb in a tin cylinder, 5 in. by 3 in., and Hillite grenades, in the form of a 4-in. spherical tin fitted with a " sparklet " bulb or a tin cylinder of 3 in. by 3 in., were issued for trials; but bulk supply was not undertaken in view of unfavourable reports received from France during the autumn. In October, 1915, the S.K. glass containers, which had been produced at the rate of 4,000 weekly from the preceding August, were replaced by a cast-iron spherical grenade, which was less dangerous to manufacture. This was the M.S.K. grenade intended for mechanical propulsion. Supply of all types, either irritant or lachrymatory, ceased temporarily in January, 1916, when a general decision was taken at General Headquarters against the use of chemicals in grenades. Issue of special grenades was resumed in the spring of 1917 in accordance with a request received from France in the previous autumn for chemical hand grenades to clear dug-outs. After detailed experiment, the M.S.K. spherical cast-iron type was re-introduced as a service grenade (No. 28) with a non-persistent lethal filling. This grenade was supplied continuously in considerable quantities while hostilities lasted. In 1918 it was supplemented by comparatively small numbers of the Hillite

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[1] D.M.R.S. 262 H.

[2] Appendix XIII.

[3] Hist. Rec./H/1600/14, III. 62.

[4] Based on Hist. Rec./H/1650/9, 10.

grenade, re-introduced as No. 33, and by a third chemical grenade, the No. 41.[1]

The use of grenades for smoke production was continuous from June, 1915, when a red phosphorus grenade was sanctioned, not only as a smoke producer, but also in view of the moral effect at first expected from its incendiary properties. Supply was immediately organised at the rate of 1,000 a day, and this grenade (No. 26) became a service store of which more than a million and a half were issued during the war. About July, 1915, an incendiary phosphorus grenade was evolved to destroy the long grass which afforded cover between the trenches. This was the Threlfallite bomb, a tin cylinder, 3 in. by 3 in., filled with white phosphorus, oil and petrol. Experimental supplies of Fumite (white phosphorus) grenades were also issued with a view to providing a stopgap smoke producer. The Fumite and Threlfallite grenades issued as emergency types together numbered 120,000. The No. 26 (hand) smoke grenade was replaced very slowly by the No. 27, a combined hand and rifle grenade filled with white phosphorus, of which the pattern was evolved late in the year 1916. In the spring of 1918 steps were taken to substitute for No. 27 a somewhat similar grenade designed for use with a discharger cup.

The development of the rifle grenade as a means of signalling followed naturally upon the use of smoke grenades. The design of the first service grenade for daylight signalling (No. 31) was worked out *pari passu* with the No. 27 smoke grenade towards the end of 1916. It consisted of a tin cylinder about 7 in. by 2¼ in., with a steel disc in the base to take the rifle rod. The shock of discharge from the rifle set back a striker firing the percussion cap, to which was attached a small length of safety fuse. The fuse ignited an opening charge, setting free smoke of several colours. Two similar grenades were used for night signalling—the one type (No. 32) containing a parachute, from which were suspended stars of various fixed colours, while in the other (No. 38) the stars changed colour. When, in the summer of 1917, the adoption of a discharger cup enabled rifle grenades to be fired without a rod,[2] the three types of signal grenade were modified for this method of firing. A cylinder of rolled brown paper with a wooden bottom and a tin lid secured by adhesive tape took the place of the former tin cylinder. On the base was a tin disc, and the wood and the disc were pierced to allow the flash from the ballistite cartridge in the rifle to ignite a time fuse, firing the bursting charge and also a quick-match connected with the contents of the cylinder. This, in the case of the daylight signal (No. 42), which replaced No. 31, was a coloured smoke candle suspended by an asbestos string from a parachute. The stars in Nos. 43 and 45, which superseded Nos. 32 and 38, were respectively of fixed or changing colour.[3]

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[1] Appendix XIII.

[2] See below, p. 86.

[3] HIST. REC./H/1600/14, III., pp. 58, 63.

(c) MODIFICATIONS IN DESIGN.

Considerable improvements in design were effected during the period under consideration. Among the most important of these was the entire remodelling of the Mills grenade in the summer of 1917 by the rearrangement of the firing mechanism to prevent prematures, by the enlargement of the filling hole to expedite output, and by various contrivances to protect sensitive parts from atmospheric conditions.[1] The remodelled grenade (No. 23, Mk. III) was issued alongside Mark II until large stocks of both had accumulated in France in March, 1918. Steps were then taken to replace both classes of rifle grenade, viz., the Mills hand and rifle No. 23 and the rifle grenade No. 35, by a rodless form of the Mills grenade (No. 36), which had been introduced into service use about the middle of 1917.[2]

Until this date all British rifle grenades had been fired by means of a steel rod, which simplified their use, but had several grave disadvantages. The rods were inconvenient and heavy to carry. The shorter rods added to the wear of the rifle by causing the propellant gases to recoil against the barrel at high velocity. The longer rods augmented the range, but increased recoil, stressing the rifle beyond its strength.[3] The Mills grenade (No. 36) was fired by means of a discharger cup, based on the principle of a French device. The cup was attached to the muzzle of the rifle. To the base of the grenade there was fixed a gas-check, consisting of a steel disc 2½ in. in diameter, which fitted into the cup exactly, thus receiving the entire pressure upon discharge.[4] The discharger cup eliminated the need for the cumbersome rifle rod, and increased the range by two and a half times, but it could only be used with time-fused patterns, such as the Mills grenades, because the grenades might strike the ground in any position, and so far the percussion arrangements in British designs depended upon the grenades' striking nose first.[5] Output of grenade No. 36 began in the third quarter of 1917, and by the end of 1918 was almost equal to that of the rodded Mills grenade (No. 23).[6]

Rifle grenades underwent certain other developments during the last two years of the war. In May, 1917, investigations were made with a view to re-designing the Pippin grenade, manufacture of which had been recommenced towards the end of the previous year.[7] Comparatively small quantities of this grenade were supplied throughout the year and during the first three months of 1918, after which issue ceased[8] in favour of the modified forms of Hale and Mills grenade, in which the factor of safety was higher.[9] Again, experiments during 1917 led to the evolution of an improved form of percussion rifle grenade. Those already in existence had the disadvantage that

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1 HIST. REC./1600/14, III. 46.

2 D.M.R.S. 262 H.

3 HIST. REC./H/1600/14, III. 64.

4 *Ibid.*, 46.

5 *Ibid.*, 67.

6 Appendix XIII.

7 HIST. REC./H/1640/1, pp. 25-50.

8 Appendix XIII.

9 HIST. REC./H/1600/14, III. 54.

detonation took place in soft ground only after the grenade was partly buried. In addition, vital parts were subject to corrosion due to the exudation of the explosive, and the grenades thereupon became extremely dangerous to handle or fire. These drawbacks were obviated in the new pattern of rodded rifle grenades, known as the Steuart, or No. 39. Direct action on impact was secured by a re-arrangement of the striker on an entirely different principle. The action of the explosive upon essential parts was prevented by enclosing it in a waxed paper container.[1] Output of the Steuart grenade began in the spring of 1918, and nearly a million had been issued before the close of the year.[2]

Although service use of percussion hand grenades had been abandoned in May, 1916, investigations continued with a view to producing a design which should detonate whatever the angle of impact. An "Allways" fuse was adapted from a German trench mortar fuse for this purpose in the R.L. ball grenade evolved about March, 1916. This pattern was subsequently developed into the Humphries grenade to meet new conditions laid down by the Trench Warfare Committee. Other types of percussion grenade, such as the Chamier and D.C., were tested and abandoned in 1917.

New conditions to govern the design were formulated during that year. The new percussion grenade was to be capable of use by hand or with the rifle, as was the case with the new Mills time grenades. It was to be suitable for firing from the discharger cup brought forward in the summer of 1917. During the following year systematic comparative trials were undertaken with a view to providing an all-round percussion grenade on certain fixed lines. A special grenade sub-committee was formed for this purpose in August, 1918, and was continuing its investigations at the date of the Armistice.[3]

(*d*) FLUCTUATIONS IN PROGRAMME.

Constant and enormous fluctuations in the demand continued to be the main difficulty in organising the supply of all classes of grenades throughout the war. During 1916 the weekly demand for the Mills grenade had risen from 250,000 to a million, then to 1,400,000. A stock of four millions was accumulated at the request of the War Office, and output was increased in order to supply the needs of the French army. At the same time, the demand for issues overseas was always considerably below the formal requirement, with the result that large stocks accumulated, and the question of storage became a grave problem. This difficulty was partially overcome by a revision in the demand in December, 1916. Storage accommodation was expanded and the number of grenades supplied to the French Government increased; but the surplus was still so large that all contracts were cancelled.[4]

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[1] HIST. REC./H/1600/1, III. 55.

[2] Appendix XIII.

[3] HIST. REC./H/1600/14, III., pp. 65, 67.

[4] D.M.R.S. 262 A; HIST. REC./H/1640/1, p. 16.

Similar conditions affected the supply of rifle grenades. Expenditure during the autumn of 1916 was considerably below output, even though this had not reached the formal requirement for 150,000 weekly. Moreover, the introduction of the combined hand and rifle grenade considerably reduced the demand for grenades for use with the rifle alone. In February, 1917, the demand was reduced to 250,000 monthly.[1] Contracts were accordingly cancelled, and the whole organisation for the supply of this type of grenade was broken up, only to be rebuilt, with considerable difficulty, in order to meet an increase in the demand received later in the year.

These fluctuations were due to difficulty in estimating actual expenditure, as well as to the normal changes in tactical requirements. There were considerable practical difficulties in calculating the numbers used as a means of estimating future needs, owing to the enormous quantities involved and the amount of work entailed in tracing consignments after issue overseas.[2] The introduction of new types aggravated the problem. Thus in March, 1918, it was anticipated that the introduction of the Mills grenade No. 36 for use with the discharger cup would have very considerable effects upon demands for other types; but these had not then been ascertained, and in any case they depended upon the supply of the cups themselves. The rebuilding of output during the previous year had resulted in the accumulation of large stocks of Mills grenade No. 23, which would serve as a safeguard in the event of the failure of the new type. The weekly requirement was therefore reduced to 25,000 only, and the demand for rodded percussion rifle grenades (No. 35) was also decreased,[3] and was subsequently cancelled entirely.[4]

Later in the year it was agreed to meet the new position by maintaining a fixed reserve of the chief types in use: a million and a half of the Mills grenade (No. 23), a million of the new type of Mills grenade (No. 36), and half a million rifle percussion grenades (Nos. 20, 22, 24 and 35), in addition to certain stocks of special grenades. In July, 1918, it was decided that stocks of the No. 23 grenade, amounting to about 4,000,000 then overseas at Gaillon, together with existing commitments would meet running requirements for grenades in full for a considerable period. Arrangements were made for converting the entire stock at Gaillon into the newer pattern (No. 36), for which the weekly demand was fixed at 300,000 in September, 1918. All demands for rodded percussion rifle grenades were cancelled, except for the Steuart grenade, of which 100,000 weekly were to be supplied for six months from August, 1918, onwards. Large stocks of filled grenades remained unexpended at the close of the war.[5]

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[1] D.M.R.S. 262 A.

[2] D.M.R.S. 262, 262 A.

[3] D.M.R.S. 262 H.

[4] D.M.R.S. 262 A 2.

[5] *Ibid.*

IX. Summary.

The British Army began the war equipped with one design of percussion hand grenade, which was only capable of manufacture in extremely limited quantities, and was produced by the Ordnance Factory, Woolwich, alone. For more than a year of trench warfare the main supplies received from home consisted of some thousands of this type and of two others, the monopoly of a single firm. One of these was a percussion hand grenade, the other a rifle grenade. They were supplemented by larger quantities of time-fused grenades, inferior in safety and efficiency, which were extemporised by the troops themselves or made at home under circumstances of great urgency.

The turn of the tide came with the introduction of the really efficient and safe time-fused Mills grenade, of which nearly five millions were produced by the end of 1915. During the last six months of the year grenade making was organised among numerous firms, many of which owned quite small works with less than a score of employees, while at others, which were engaged also in more important munition work, the numbers of employees occasionally exceeded 2,000. The Ordnance Factory and the one monopolist of 1914 were thus replaced by more than 200 contractors drawn from all kinds of metal workers. Manufacture on the group system was organised among Birmingham firms. Grenades were produced by textile machinery makers, motor-engineers, cycle-makers, and by manufacturers of bedsteads, fenders, gas meters, vacuum stoppers, sparklets, saws, confectionery machinery and all kinds of domestic fittings. The finer work on the small parts was undertaken by the Birmingham brass-founders, by dental instrument makers, and by manufacturers of bolts and nuts, toys, locks, bells and fishing tackle.

These efforts were only beginning to bear fruit in the autumn of 1915, when the Battle of Loos was fought with emergency grenades, chiefly of the unpopular Ball type. Shortly before this offensive the Army in France was equipped with 364,005 grenades, of which more than two-thirds (288,092) were of the Ball type, and a considerable number (56,315) of another stopgap, the Pitcher grenade. Next to these in number was the Mills grenade, of which 11,484 were stored at Boulogne and several thousands about to be received from home. The nature of the remainder is of some interest, and is shown in the table below.[1] The Army was enabled to dispense entirely with the less satisfactory stopgap hand grenades from November, 1915, onwards. Local manufacture of one design of rifle grenade, the Pippin, was continued by the armies in France, who produced three millions of this pattern, while the home capacity for grenades was still under organisation. Its reproduction was subsequently undertaken at home, but it was eventually superseded by safer modifications of the service

[1] Grenades in France on 11 September, 1915: No. 1, 1,300; No. 2, 40; No. 5, 11,484; No. 6, 1,960; No. 7, 154; Ball, 288,092; Threlfallite, No. 1, 90; Threlfallite, No. 2, 419; rifle, 165; chemical, 3,986; Pitcher, 56,315; total, 364,005.

patterns. In May, 1916, it was decided to abandon in favour of the Mills grenade the earlier patterns of service percussion grenades. Meanwhile the capacity for these had been built up slowly and laboriously, and had almost reached the total requirement when they were withdrawn from use. Considerable financial loss resulted from the withdrawal of the percussion and emergency grenades, although provision was made in some cases for the allocation of surpluses to the Allies, in others for breaking down the obsolete patterns into their component parts.

Output of the Mills grenade reached its zenith during the fourth quarter of 1916, but the expenditure both of hand and rifle grenades during the summer campaign had fallen considerably below the numbers estimated. Large stocks accumulated. A market for a certain proportion of the surplus was again found with the Allies. Contracts were closed down, and in the case of the rifle grenades the organisation was brought to a complete standstill.

At the same time measures were taken to improve the types in use. The Mills grenade was adapted for discharge from the rifle during the summer of 1916, and subsequently for combined use either by hand or from the rifle, a form in which it had entirely superseded the Mills hand grenade by the autumn of 1917. The older pattern of percussion rifle grenade passed meanwhile through several modifications until at length, in the last few months of the war, these were replaced by a safer and more efficient type, of which the first million had been produced by the end of 1918.

Output of the various types of percussion rifle grenades had been rebuilt with some difficulty to meet increased demands during the year 1917. It reached its climax in the first quarter of 1918, during which nearly two millions were produced. These were all fired by means of a rod, which was an inconvenient addition to the bomber's equipment and increased the wear on the rifle. In the spring of 1918 a new form of the Mills grenade (No. 36), dispensing entirely with this rod, was introduced into the line. It was modelled on the most recent form of Mills grenade. This remained the popular type for general use, although it was supplemented in 1917 by a lighter Egg grenade, and was superseded for particular purposes by special patterns, such as the anti-tank grenades.

At the close of the war, steps were being taken to convert all existing Mills grenades into pattern No. 36, in order that they might either be thrown by hand or fired from the rifle by means of a discharger cup. Large stocks of filled grenades existed. Enormous numbers had been produced and expended. Output of Mills grenades alone had reached 75 millions during the war. Moreover, four years' experience in the use and manufacture of these weapons, together with close and systematic investigation as to the problems affecting their design, had produced a mass of information which was already being applied to future developments, in particular to the evolution of a satisfactory percussion grenade for use either by hand or from the rifle.

CHAPTER V.

SPECIAL WEAPONS AND MISCELLANEOUS STORES.

I. Bomb Engines.

The trench mortar proper throws bombs by means of a propellant charge. Another class of weapon, investigated in some detail and used to a limited extent in the first emergencies of trench warfare, consisted of bomb engines, such as pneumatic, spring and acetylene guns and catapults, for propelling missiles by purely mechanical means. The use of these contrivances was seriously investigated during the year 1915, particularly by General Jackson, who regarded them as an important means of hurling into the enemy's trenches a continuous stream of missiles, explosive and chemical.[1] Two engines, the Leach catapult and the West spring gun, came into actual supply and were issued in considerable numbers, their production being due to General Jackson's representations that the infantry in the trenches should be furnished with thousands of propellers in order to bombard the trenches by day and night.[2] Both of these engines had the advantage over trench mortars in one respect, viz., that they were silent.[3]

An experimental order for the Leach catapult was placed in January, 1915[4]; General Headquarters, France, reported favourably on the machine, 18 February, 1915, at the same time asking for the immediate supply of 100 engines, and later for twenty to each division.[5] Improvements in the design were made while manufacture continued, and at the end of June the catapult could throw a 2-lb. weight about 200 yards.[6] The orders at this date were for 3,000 machines in all, of which about 200 were issued by the end of June. Subsequently a further contract was placed with the same firm for another thousand of a new pattern.[7]

The accuracy of the weapon depended upon the quality of the rubbers, and the main difficulty in production was to supply rubbers which did not readily deteriorate.[8] By the end of October, 1915, 3,152 catapults had been delivered, the ammunition used being

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[1] Hist. Rec./R/1600/19.

[2] *Ibid.*, H/1600/8.

[3] *Ibid.*, H/1600/14, Chap. III., pp. 78-80.

[4] *Ibid.*, R/1660/19.

[5] *Ibid.*

[6] *Ibid.*, H/1600/14, Chap. III. 80.

[7] 94/C/314; F.W. 3, Branch Memorandum 9, 178; T.W. Branch Memorandum 2455.

[8] Hist. Rec./H/1600/17, Chap. III. 80.

emergency grenades of the Ball and other types, filled with high explosive or with irritant mixtures. It was then proposed to replace the Leach catapult by another type of French origin, viz., *Sauterelle A.*[1] Manufacture was accordingly limited to the production of spare parts, and the catapults in stock were issued to France and the Mediterranean, one hundred being reserved for despatch to Serbia.[2] No issues were made after 19 February, 1916, and the use of catapults was entirely abandoned in the following March.[3]

The West spring gun was developed by Captain A. West early in 1915. Its efficiency was about equal to that of the catapult, but the spring gun was very much heavier and more expensive. It was accurate and silent, but its range was short and it needed a larger emplacement than did a trench mortar, while its cocking lever was liable to be seen above the emplacement. Its power was supplied by twenty-four springs acting on a throwing lever and discharging the bomb from a cup, the type of cup most used being a wooden V-shaped block. Manufacture of the guns was suspended early in October, 1915.[4] Considerable delay occurred in producing the special spherical bombs or grenades as ammunition. Before these were forthcoming in adequate numbers, the requirement for spring guns was cancelled in March, 1916, in view of the availability of more satisfactory weapons. The Stokes mortar had meantime been developed and produced in bulk. Manufacture of the rifle grenade had been placed upon a more satisfactory basis than before. These weapons were more efficient and less dangerous than the catapult or the spring gun. Accordingly, in March, 1916, General Headquarters, France, cancelled the demand for both contrivances, desiring that all the remaining catapults should be scrapped, a " more economical way of dealing with them than issuing them to the troops."

II. The 4-in. Stokes Mortar.

The mechanical engines supplied in 1915 were chiefly intended for hurling special bombs or grenades filled with irritant or lachrymatory mixtures. On 30 July, 1915, orders were placed for 20 complete Stokes mortars of 4-in. calibre, which it was General Jackson's intention to provide for use with special ammunition. This mortar eventually became the standard type for discharging smoke and chemical bombs.

When Mr. Lloyd George sanctioned the manufacture of 1,000 Stokes mortars on 12 August, 1915, it was arranged that 800 should be of the 3-in. pattern and 200 of the 4-in. The telegraphic request for Stokes mortars with smoke ammunition on 22 August, was the first formal demand received.[5] Little progress had then been made

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[1] T.W. 2455.

[2] *Ibid.*

[3] (Printed) *Weekly Report*, No. 30, III. (19/2/16).

[4] *Ibid.*, No. 10, III. (2/10/15).

[5] See above, p. 42.

in the manufacture of the barrels for the twenty mortars already ordered; but an extraordinary effort was immediately made to issue a number of these with smoke bombs to France in time for the offensive at Loos. This was effected by issuing unproved mortars, thirty of which were manufactured and despatched by mid-September,[1] the Army Council repudiating any responsibility for these improvised stores. The ammunition consisted of a papier-mâché shell attached by a short sheet-iron casing to a gun-metal firing base. The filling was red phosphorus in a cylindrical tin container.[2] In view of difficulty experienced in ensuring a central blow to the percussion cap a striker-clip was designed to slip over the head of the propellant cartridge, which was thus fired by the striker of the clip upon the impact of the bomb with the bottom of the mortar tube. The parts for 10,000 shells were shipped separately and assembled at Advance Headquarters of the First Army.[3] These thirty howitzers with one sample weapon retained by the department[4] were the only 4-in Stokes mortars despatched to France during the year 1915. Supplies of smoke ammunition for the 2-in. mortar never passed beyond the experimental stage.[5]

During October and November, 1915, endeavours were made to produce a design of 4-in. bomb with high explosive filling[6]; but it was finally decided on 19 January, 1916, that this type of mortar should be used exclusively with smoke ammunition. Recent trials to test the propellant charges had then given such irregular results that it had been reported that the mortar would be useless on service without improvement in this respect.[7] By July, 1916, 200 4-in. Stokes mortars were in action in France; but the equipment was still considered unsatisfactory, particularly in regard to the mounting.[8] An improved mounting was designed during this year and received approval on 3 February, 1917.[9] Later research on the mortar and its equipment had not materialised by the end of the war.[10] The total number produced from the date of the issue of the improvised mortars in September, 1915, until the close of 1918 was 1,123.[11]

In the spring of 1916 lachrymatory ammunition was adopted for this mortar in addition to smoke bombs. A pattern of S.K. bomb was approved for service on 3 April, 1916,[12] and an alternative filling with

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1 HIST. REC./H/1610/13; T.W. Contract 988.
2 HIST. REC./H/1650/9, II. 106.
3 *Ibid.*, R/1610/14; *ibid.*, H/1611/6.
4 T.W. Contract 988.
5 HIST. REC./1650/10, p. 232.
6 *Ordnance Board Annual Report*, 1915, p. 428.
7 D.G.M.D./G./110.
8 C.R./T.W.D./1119 (3).
9 D.G.M.D./G/279.
10 HIST. REC./H/1600/14, Chap. II., p. 13.
11 Appendix X.
12 T.W. 4834.

P.S. was sanctioned in the following September. A "spot" demand for 200,000 smoke and lachrymatory bombs for issue in June was made in the preceding May, and a new requirement for 15,000 rounds weekly was formulated in the following August[1]; but actual output fell far below this figure, the total number of bombs produced during the latter half of 1916 amounting to 9,606 only.[2] The manufacturing difficulties experienced were considerable. The bomb was designed in steel and afterwards in cast-iron for simplicity of manufacture; but it proved difficult to obtain castings of uniform weight and thickness and to avoid porosity. These initial problems were not fully overcome until the summer of 1917, when the number of rejections was decreasing daily, and the firms engaged on these stores had acquired sufficient experience to work to the high standard required.[3]

These difficulties were enhanced by constant changes in design, which were largely due to adoption of new mixtures as fillings. Eleven different kinds of filling were used with Stokes bombs and projector drums in order to attain the tactical variety on which success depended in gas warfare.[4] Until the spring of 1917 the use of smoke ammunition with the 4-in Stokes mortar considerably exceeded that of gas bombs; but these proportions were reversed during the last nine months of that year.[5] In August, 1916, a demand had arisen for lethal ammunition for this mortar, and experiments were immediately undertaken to evolve a pattern of steel or cast-iron bomb filled with C.G. and various other mixtures. While these researches were in hand the troops in France improvised lethal bombs for the 2-in. mortar, and these were replaced by similar ammunition which was issued from England until the 4-in. lethal ammunition came into supply in the autumn of 1917.[6]

During 1917 and 1918 experiments were undertaken with a view to testing bombs suitable for the various fillings introduced and to improving range and accuracy by the use of vaned or stream-lined bombs.[7] The requirement for chemical bombs was increased to 30,000 weekly in March, 1917, but dropped to 22,500 weekly in the following June and diminished to zero by the spring of 1918 with the development of the Livens projector and the increase in the demand for poison gas in artillery shells.[8] The total output of lachrymatory and lethal ammunition for the 4-in. Stokes mortar was about 620,000 rounds; the total output of smoke ammunition, consisting of bombs filled with red or white phosphorus, was 170,000.[9] The adoption of chemical fillings for natures other than the 4-in. Stokes was under consideration during 1918.[10]

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[1] Hist. Rec./H/1650/10, pp. 98-99.

[2] Appendix X.

[3] Hist. Rec./H/1610/10.

[4] X./C.W./2078.

[5] *Ibid.*

[6] Hist. Rec./H/1650/9.

[7] *Ibid.*, 1600/14, Chap. II., pp. 13-14.

[8] *Ibid.*, 1650/10, p. 99.

[9] *Ibid.*, p. 254.

[10] *Ibid.*, p. 101.

III. Gas Cylinders.[1]

The use of special grenades to be thrown by hand or from bomb engines was a temporary measure adopted in 1915 to provide some means of chemical warfare pending the development of the gas cloud discharged from a cylinder.[2] The form and size of these cylinders was discussed at Runcorn at a conference between Colonel Jackson, his chemical advisers, Major Foulkes and the military attachés of allied countries on 4 June, 1915. Two types were then tried, the one the ordinary commercial cylinder, 8 in. in diameter and 5 ft. 6 in. in length, the other a lighter type of special design. It was decided to use a modification of the commercial cylinder, and in order to obtain as many as possible within the time available diversity was allowed in the length and diameter, but not in cubic capacity. The valves used were of commercial pattern; the discharge pipes at first provided proved difficult to conceal and to manipulate and were replaced, after the first attack at Loos, by rubber pipes improvised from ordinary garden hose.[3]

The first consignment of 100 cylinders was despatched on 10 July, 1915, and by 25 September some 6,000, containing about 180 tons of chlorine, had been sent to France. The first surprise attack with cloud-gas discharged from these cylinders took place on 25 September, and a second discharge was made on 13 October, after which steps were taken to vary the gas used, but the provision of cylinders was continuous, as they were utilised in exporting chlorine delivered to the French Government. The employment of cylinders for the double purpose of transport and discharge became a considerable difficulty in meeting later demands. During the first six months of 1916 difficulty was experienced in obtaining cylinders and valves in competition with other war work, particularly the production of hydrogen cylinders for the Admiralty; but by the end of July, 1916, 91,200 cylinders had been delivered to France, and between June, 1916, and March, 1917, the period during which the use of cylinder-gas reached its zenith, 42,559 cylinders were discharged on the Western front.[4]

The supply of newly-made cylinders was supplemented from those returned from France. At first these were cleaned, tested, and re-filled by the chlorine makers. In September, 1916, this work was transferred to a distinct station which was established under a contractor at Bucknall Sawmills, near Hanley, where evacuating chambers were established and washing, drying and testing arrangements installed. The station was nationalised in July, 1917, and 360,000 cylinders were handled entirely by women workers drawn from the Potteries.[5] In

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1 Based on HIST. REC./H/1650/10, pp. 44-54.

2 See above, p. 84.

3 HIST. REC./H/1600/14, p. 110.

4 X/C.W./2078.

5 HIST. REC./H/1650/4, Appendix; HIST. REC./H/1122. 7/9.

one case, where the nature of the gas necessitated special apparatus, the evacuation of the returned cylinders was carried out at another national factory (Langwith), then engaged upon chemical manufacture.

From March, 1917, onwards cylinders were supplemented and outpassed by artillery shell and projector drums as a means of discharging gas. The whole number of cylinders despatched throughout the war was 224,000 and the emplacement sets provided numbered 4,900.

IV. Flame Projectors.[1]

The first German *flammenwerfer* attack against British trenches took place at Hooge on 30 July, 1915. Some time before, the French army had captured *flammenwerfer*, and thus the nature of the enemy's weapon was not entirely unknown.[2] Mr. Joseph Menchen, an American, had already laid before Colonel Jackson a proposal for utilising a petrol-spraying apparatus of his own design, and had been asked to develop two suitable patterns, the one for a heavy battery to be embedded in a trench and give the longest possible throw; the other of a light portable type similar to that used by the enemy. A design of this second kind had been evolved in April, 1915, but permission to manufacture had been withheld.[3]

The heavy battery designed by Mr. Menchen consisted of a series of oil-tanks, connected up with a number of air cylinders, which provided the pressure for discharge. It threw a jet of burning oil about 100 yards, but was too complicated and clumsy for efficient use in the trenches. After studying a French pattern, the Hersent type, Captain Vincent, of the Trench Warfare department, evolved a four-cylinder apparatus, or Quad-Battery, in collaboration with a firm which had already had experience in the manufacture of compressed air machinery. Trials were held before the Master-General of Ordnance on 6 August, 1915, and on the following day the Secretary of State for War gave instructions to proceed with the apparatus. Authority to construct 500 four-cylinder groups for stationary use was given by Dr. Addison, on behalf of the Minister, on 9 August, when he also sanctioned the production of caterpillar pedrails for carrying flame-projectors, the development of which had already been undertaken by Colonel Jackson in June, 1915.[4] The authority to make four-cylinder batteries was subject to revision in the light of financial estimates. On 30 September, after satisfactory trials with the Quad-Batteries, sanction was given to order fifty sets at £250 each. It was then anticipated that, failing their use in the trenches, these batteries could be mounted on the pedrail vehicles, or used to meet a known demand among certain of the Allies.[5] The cost of

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[1] Based on Hist. Rec./H/1600/14, Chap. IV.; 1650/1, 6.

[2] T.W. 700.

[3] Hist. Rec./H/1600/8.

[4] See Vol. XII., Part III., p. 22.

[5] T.W. 1590.

the battery, modified by the addition of a "monitor," averaged £450, without any spare oil supply tanks or air cylinders.

Parts for the fifty sets were made by different specialised firms, and assembled in the shops of a single contractor at Glasgow. They were first used for training Russian soldiers at Wembley in April, 1916, and during the summer thirty-six were sent to Russia. Three others were issued to France for the battle of the Somme, but decision was taken against their further use, since their effect in the offensive was out of all proportion to the amount of labour needed for their installation. Out of the remaining eleven, seven sets were fitted up on H.M.S. "Vindictive" for the attack on Zeebrugge Mole in April, 1918.

Certain attempts were also made to evolve portable projectors, but their range was small, varying between 25 and 48 yards. Trials of a portable knapsack projector were made in November, 1915, and steps were taken to supply fifty of these.[1] They were of the Morris pattern, for which certain parts of the Menchen design were adopted, but the factor of safety was increased by an arrangement for the immediate discharge of the entire contents at the first shot. Although fifty of these machines were issued to France, their general use was prevented by the weight, which was prohibitive for a knapsack type, while the size was too small for a semi-portable pattern. Another pattern, the Lawrence knapsack projector, was demonstrated in Russia, but the supply of some thousands subsequently requested by the Russian Government did not materialise. Other smaller flame-guns of later design did not pass beyond the experimental stage, with the exception of the Hay machine, which was supplied in some number for use from H.M.S. "Vindictive" in the attack on Zeebrugge.

The only type of flame-projector which was regularly and successfully used by the British Army was the Livens large-gallery battery. This pattern was evolved by Captain W. H. Livens, in co-operation with his father, Mr. F. H. Livens, of the firm of Ruston, Proctor & Co., of Lincoln, who were the manufacturers. It consisted of seven 9-in. oil pipes coupled up to form a continuous pipe, which was placed horizontally on the floor of an underground gallery. Five steel cylinders resting above the pipe contained oil for a second and third discharge. The shot was fired by means of high-pressure gas from a number of gas bottles arranged vertically in the rear of the apparatus. An "equaliser" between the bottles and the oil pipes enabled the gas to follow up the oil as quickly as it was discharged, thus giving a maintained full length of range. The construction of the "equaliser" was a matter of considerable difficulty, as the test pressure required was 1,800 lb. per sq. in. and a good deal of oxy-acetylene welding was needed. The cost of the battery was about £550, exclusive of gas bottles. The range obtained was 110 yards. It was therefore necessary to take the apparatus forward in a mine-shaft. It was thus completely concealed, and discharge was effected by means of a

[1] Unregd. Memo. with T.W. 1590; T.W. Contract 1391, 1392.

"monitor," which was worked on the principle of a hydraulic ram for a lift, and raised the nozzle above ground at the last moment before the shot was fired, lowering it again immediately afterwards. Various materials were tested with a view to lightening the weight of the apparatus for transport. A light steel was generally used, with oxy-acetylene welding. A scheme for making a cylinder of duralumin was abandoned, mainly on account of the prohibitive cost of the metal and the difficulty of working it.

The large-gallery batteries were used effectively in July, 1916, for the opening phase of the battle of the Somme; but the limited range restricted their success to the main purpose of silencing the German machine guns at the moment of attack. The necessity for installing them in mine-shafts limited their use to the first phase of an offensive on an old-established front; and in all they were only discharged on fourteen occasions. They were rapidly superseded by simpler weapons of less cumbersome form, such as the Livens projector, which was first improvised as a flame-projector and afterwards adapted for discharging gas.

V. The Livens Projector.[1]

In the trenches gas was discharged by means of hand grenades and cylinders in 1915, from cylinders and the 4-in. Stokes mortar in 1916. From 1917 onwards the Livens projector and drum was used in addition to the three former methods.

The development of this projector dates from the summer of 1915, when Captain W. H. Livens began investigating the problem in collaboration with his father, Mr. F. H. Livens.[2] As an officer of the Special Brigade, Captain Livens obtained experience of the actual conditions of trench warfare in France, and improved the methods of discharge from the cylinders used in the first cloud-gas attack on 25 September, 1915. He concluded that a single salvo of thin-walled bombs from about a thousand mortars would be an ideal means of forming a gas-cloud, and would have the additional advantage of reducing the number of men needed for making emplacements and for firing the mortars. Intending to produce a weapon so easy to manufacture that large supplies could be readily obtained, the inventor evolved a pattern of extreme simplicity. The first projectors were improvised in the field by the Special Brigade in July, 1916, for an attack against machine-gun posts near La Boiselle and were used with great success to fire drums of boiling oil. The range obtained (200 yd.) with the new projectors was double that of the large-gallery flame-projectors already employed and their use was far simpler.

The improvised projectors consisted of simple tubes formed by removing the top from steel oil drums, 20 in. high and 12 in. in diameter.

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[1] Based chiefly on HIST. REC./H/1600/14, Chap. IV.

[2] HIST. REC./H/1650/1, Appendix.

They were planted in the ground at an angle of 45 degrees. The projectile used was the ordinary A.S.C. lubricating oil can. These broke up on impact and ignited themselves by streamers of oily sacking, which were fired by the flash of discharge. The next step was to obtain from home a slightly modified form of these stores which for secrecy were demanded by the Commander-in-Chief under the name of "oil drums" and "portable cans for carrying oil up trenches." By close co-operation between Captain Livens and the Trench Warfare Supply department, it was ensured that the drums were 4 ft. by 9 ft. 5 in., and the cans were provided with a separate compartment which contained a Mills grenade as a priming charge. Black powder was used as the propellant charge.

Pending issue of these "oil drums" and "portable cans," the improvised projectors were used with considerable success for discharging gas at Thiepval in September, 1916, and at Beaumont Hamel in the following November. By this date the purely experimental stage was past. A demonstration before the Director of Gas Services took place at the Porton Experimental Ground in December, 1916,[1] with the result that a formal requirement was made for 15,000 projectors and 50,000 drums.[2] Formal approval of a chemical filling was given on 7 March, 1917, and two other lethal mixtures were subsequently adopted without any modification in the type of drum.[3]

About the time of the Porton demonstration, Captain Livens adopted for the projector certain spare lengths of the 8-in. oxy-acetylene-welded tubing made by certain contractors for the Admiralty. With this it was found possible to get a range of 1,300 yd. Throughout later modifications this calibre was retained; but the length of the projector was varied to obtain different ranges. The light type was 2 ft. 9 in. long, the medium was 3 ft., and the heavy, long-range projector 4 ft. 3 in. The base-plate was a "dish" of steel, resembling in shape a Chinaman's hat. The drum in its final form was a light steel cylinder strengthened by a central tube which held the gaine or bursting charge. The firing arrangement, a combination of Bickford fuse with a ·410 cap, was adopted from the Stokes mortar. The ratio of the weight of the gas-content to that of the empty projectile compared very favourably with that of the 4-in. Stokes bomb and still more favourably with that of the average chemical shell.

In order to economise manufacturing capacity, particularly machine tools, the projector was neither bored nor turned and the machining of the drum was reduced to two small operations. In consequence, large tolerances were allowed in the sizes of projectors and drums. In order, therefore, to prevent the escape of gases on discharge, a charge-box was developed with a steel gas-check to fit the mortar barrel. This form of charge was introduced in 1917 together with flaked cordite as a substitute for black powder, for which insufficient milling capacity existed.

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1 HIST. REC./H/1650/9, III. 258.

2 *Ibid.*, 1650/1.

3 *Ibid.*, 1650/9, III. 261, 265.

The first projectors manufactured in bulk were issued in time for a salvo of 2,000 to be fired at Vimy Ridge in April, 1917, little more than three months after the formulation of the demand. The gas-check was in supply shortly after this. It increased the range to 1,800 yd., at the same time preserving the simplicity of the weapon. Considerable difficulty was experienced in the initial stages of its manufacture. The withdrawal of approval for the old pattern propellant before supply of the new charge-boxes was assured was assigned as a reason for a considerable discrepancy between the numbers of drums and propellants available in September, 1917.[1] In March, 1917, the original requirement for 15,000 projectors had been converted into a regular demand for 3,000 drums weekly, which was raised in the following July to 4,000 weekly, and remained at that figure till the following March.[2]

The chief manufacturing difficulty was to obtain a sufficient supply of tubing for the projector, and this increased with the growing shortage of steel. The acetylene-welded tubing was replaced by fire lap-welded tubing, of which the ends were closed in by a special machine used for gas cylinders. Mannesmann weldless steel tubes were subsequently used for the longer range projectors, but there were not enough available to admit of their use for the shorter range weapons. These were still made of the lap-welded tubing originally used.[3] In view of the shortage of solid drawn steel tubes in the spring of 1918, investigations were undertaken for replacing them by wire-wound lap-welded tubing,[4] even though this was somewhat more costly than the original method. The losses in the German offensive of March, 1918, made the supply of projectors particularly urgent. Owing to unexpected delays which occurred in extending the capacity of the Mannesmann Tube Company, the supply of these projectors then competed with the output of hydrogen bottles required for naval and military kite-balloons. The deliveries of projectors accordingly fell considerably below requirements, which were modified in view of the restricted supply of raw material. The position was eventually eased by the development of the pattern of wire-wound tube which was approved in May, 1918.[5]

The projector was adopted as a service store by the French and American Governments, and was about to be used by the Italian armies at the cessation of hostilities. About 140,000 projectors and 400,000 (empty) drums were produced in Great Britain between January, 1917, and the close of 1918.[6]

VI. Helmets.

One of the most remarkable steps taken towards meeting the new conditions of warfare was the equipment of the entire British army with steel helmets.

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1 D.M.R.S. 296 P.

2 Hist. Rec./H/1650/10, p. 99.

3 Hist. Rec./H/1650/1, p. 11.

4 T.W. 9674/25.

5 D.M.R.S. 296 P.

6 D.G.P./P.R.R./3929.

The Trench Warfare department undertook to provide some form of protection for the head and neck in July, 1915. Silk necklets were manufactured in various small quantities until June, 1917, the main difficulty in this supply being the provision of the material, in competition with the large quantities of silk required for cartridge-making.

Steel helmets were produced in much larger quantities. A helmet made of four separate units and weighing 1 lb. 10 oz. had already been issued to the French troops in the spring of 1915. It afforded comparatively slight protection, being capable of resisting a shrapnel bullet, 41 to the pound, fired to give a striking velocity of 400 ft. per second.[1] In August and September, 1915, British authorities began to follow suit by making experimental types of the Brodie helmet, and towards the end of September production was organised to meet a demand for 25,000 helmets of the second type evolved ("B").[2] They were made in one unit and were of mild steel, affording protection against shrapnel at a velocity about equal to that resisted by the French helmet. Their manufacture was a comparatively simple matter, and the rate of production had reached 850 daily when, in the second week of October, decision was taken to provide a helmet of hardened manganese steel weighing 2 lb., and capable of resisting shrapnel at 750 ft. per second.

The steel for the new type of helmet was made by one firm only, Messrs. Thomas Firth & Sons, of Sheffield. It was more costly than the mild steel formerly used. There was no precedent for stamping this particular class of metal, which was of a peculiarly brittle nature.[3] It was estimated that while a million of the type originally ordered could be produced in two or three months, manufacture of the same number of the higher grade article would take from four to six months. In view of the great superiority in the quality of the hardened steel helmet, however, military authorities insisted upon the provision of the new type in increasing numbers, which by 10 November, 1915, amounted to 1,050,000. It was also desired that the balance of the orders already placed should be made of the higher grade steel.[4] In effect, the decision entailed the supply of helmets at a far slower rate, but of much better quality.

Representatives of the steel-makers were called by the supply officer into conference with Messrs. Firth & Sons, who placed at their disposal their knowledge as to the manufacture of the special steel.[5] At the end of November, 1915, negotiations were begun with Messrs. Beardmore, whose experience in making armour plate for the Admiralty had not, however, extended to steel plates of the thinness required for helmets. In conjunction with a neighbouring rolling firm, and after several unsuccessful attempts, they also evolved a steel which would satisfy the new and stringent conditions. Arrangements

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[1] HIST. REC./R/1000/97.

[2] 84/B/9539, cited in D.M.R.S. 262.

[3] C.R./T.W.D./1112 (2).

[4] D.M.R.S. 351.

[5] C.R./T.W.D./1121, f. 167.

were made with two firms, the one in Wolverhampton, the other in Glasgow, to make the stampings, work of special difficulty in view of its unprecedented nature.[1] The Sheffield Munitions Committee also organised a system under which the silver-plating trade, which had been suffering by reason of the war, should adapt for this purpose presses usually employed upon much lighter work, such as the manufacture of dish-covers.[2] The lining and fitting of the finished helmets was undertaken by the Army and Navy Stores.[3]

There were thus established three main sources of supply, viz., the Wolverhampton contractor, who was expected to supply 25-30,000 weekly; the Sheffield group undertaking output at a similar rate; and the Glasgow firm, whose rate of production was estimated at 45,000 weekly.[4] Manufacture of the new hardened steel helmets began towards the end of November, 1915,[5] the rate of supply being at first considerably below that estimated. The first 300,000 had been delivered by the middle of March, 1916, and of these rather more than 140,000 had reached the Army in France by the beginning of the month, a certain proportion having been issued to other theatres of war. On 6 March, 1916, the Commander-in-Chief, France, notified that experience with the new helmets had shown them to be a most useful protection. The average rate of head wounds among men already equipped had been reduced to less than one-quarter of the usual proportion. A more rapid rate of supply was accordingly urged in order to equip as soon as possible all the troops then in France and to provide for the new divisions as they arrived.[6] Delivery of the first million helmets was completed by the first week in July, 1916.[7] Production continued thereafter not only to meet the growth of the Army and to provide for wastage, but also to supply certain of the Allies.[8] Thus, for instance, about a million and a half British-made helmets were supplied for American troops. In September, 1917, issue was also made to the Home Commands and to special constables as protection against shrapnel from the anti-aircraft barrage.[9] The whole output by the end of the war had reached about seven and a quarter millions.[10]

VII. Body Armour.[11]

Throughout the war a very considerable amount of experiment was carried out both privately and officially with a view to producing

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1 C.R./T.W.D./1112 (1).
2 *Ibid.*, 1117 (1).
3 T.W. Contracts 1329, 1556.
4 C.R./T.W.D./1112.
5 (Printed) *Weekly Report*, No. 18, III. (27/11/15).
6 C.R./T.W.D./1112 (2).
7 (Printed) *Weekly Report*, No. 49, VII. 3 (8/7/16).
8 D.M.R.S. 517.
9 (Printed) *Weekly Report*, No. 111, IX. (29/9/17).
10 Hist. Rec./R/1000/97
11 Based, where no other reference is given, on 89/Gen. No./4385.

some form of body armour to protect the infantryman from rifle and machine-gun fire. Nevertheless, when hostilities ceased, no steel had been produced which had sufficient power of resistance and yet was light enough to be borne by the individual soldier.[1]

Both the Admiralty and the War Office were interested in the development of such protection, and shared the cost of investigating a promising composition put forward by a Frenchman, M. Dérocle, in the spring of 1915. The proposal was to utilise a special gelatine between ordinary steel plates, and experiments were carried out at the R.N.A.S. grounds at Wormwood Scrubbs; but the project was abandoned early in May, on the ground that the earlier good results had only been secured by using the composition with a special steel.[2] During the winter of 1914 and the whole of the year 1915 other investigations were undertaken, in some instances by the same *personnel*, with a view to finding a suitable plate for armoured cars, for shields on wheels, or for the landship or tank. The projects for providing the Army with some form of mobile armoured protection have been described elsewhere.[3]

The use of personal armour and portable shields was the subject of distinct investigations. In March, 1915, G.O.C., France, in answer to inquiries from the Army Council, asked for experiments to produce a bullet-proof shield for scouts or bombers, not to exceed 25 lb. in weight. Samples made by Vickers proved vulnerable to the German reversed bullet, and in August it was generally decided that the development of body armour proof against bullets at close quarters was impracticable. In the general opinion a shield was a secondary consideration to the helmet, which was then in course of development. Accordingly, the matter was dropped until December, 1915, when the Army Council again asked for information as to the utility of shields, since many offers were coming forward from inventors. On 26 December, 1915, Sir Douglas Haig laid it down that while the use of body armour proof against bullets at close range was impracticable, there was a demand for portable shields capable of being carried forward as a whole or in sections, and for some light form of protection against shell or grenade splinters to be worn by men in the trenches.

During the following year tests were made of various patterns of shields, including the Dayfield shield, made of steel similar to that used for helmets, and a special improved Dayfield pattern of splinter-proof armour, weighing 14 lb., experimental supplies of which were made in June, 1916. On 20 August, 1916, it was notified that the Army in France preferred this second design, and a request was made for its supply on a scale of 400 to the division. Thereupon the Army Council made a formal demand for 50,000 of these shields with certain modifications.[4] These were supplied in regular weekly instalments until June, 1917, when bulk manufacture began of a lighter pattern,[5] which

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[1] HIST. REC./H/1600/14, VI.

[2] 84/D/3840, 3850.

[3] Vol. XII., Part III.

[4] C.R./T.W.D./1112 (2).

[5] (Printed) *Weekly Report*, No. 94, IX. (2/6/17); No. 98, IX. (30/6/17).

weighed 6½ lb., and was considered useful under certain conditions of trench warfare. The production of the 20,000 suits of this body armour, which had been formally required, was almost complete when open warfare had again developed.

Although the utility of the armour thus provided was proved, the quantity supplied was very limited, chiefly because its weight was prohibitive as a burden additional to those already carried by the soldier. Fresh efforts were made to produce some lighter form of protection for the more vital organs during the summer of 1918. At the instance of the Minister the subject was then systematically investigated from a physiological standpoint,[1] and was dealt with in detail by the sub-committee of the Trench Warfare department, appointed in August to consider the improvement of trench warfare stores. Projects were considered for adapting articles of the infantryman's equipment, such as his box respirator or his entrenching tool, as a shield for the heart. In September, 1918, these investigations were expedited by the Minister, on the ground that anticipated developments in the means of transport would enable the soldier to enter into battle carrying some such shield; but no solution of the problem had been found when hostilities ceased.[2]

VIII. Miscellaneous Appliances.

During the first urgent year of trench warfare the authorities supplying mortars and grenades investigated the use of various miscellaneous appliances for life in the trenches. These included such articles as portable wire entanglements and mechanical trench diggers, which in most cases scarcely passed beyond the stages of experimental supply.[3] The provision of trench "furniture" was again actively considered during the last year of the war, a section of the Trench Warfare Design Committee having been established to consider devices to add to the comfort and efficiency of the troops in the trenches.[4] The activities of the Ministry in this direction were further increased by the establishment of the "Warfare" Group in July, 1918,[5] a measure taken in accordance with the Minister's policy of strengthening the impulse towards using mechanical means of waging war.[6] The main achievement of this later period was the development of various types of concrete and steel casemates, or "pill-boxes," which were manufactured in considerable numbers for experimental purposes during the summer of 1918. Aerial ropeways were simultaneously developed in connection with trench warfare, under circumstances which are described elsewhere.[7]

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1 Estab. Cent. 53/47.

2 Hist. Rec./H/1600/14, Chap. VI.

3 *Ibid.*, 1600/8; D.M.R.S. 262.

4 Estab. Cent. 53/47.

5 Hist. Rec./R/263. 024/109.

6 Vol. II., Part I., Chap. IV.

7 Vol. XII., Part V.

CHAPTER VI.

Summary.

The methods used in equipping a growing army with an absolutely new and untried class of *matériel* may well have been worth some little study. The purely military aspect of the problem does not fall within the scope of this account, but certain of its features have necessarily been considered, in view of their primary importance in the organisation of supply. Owing to lack of experience in the nature and use of trench warfare weapons, the armies could at first only formulate a very indefinite demand, and the normal formalities of a procedure which based all the activities of supply upon a precise request for a fixed number of a specified store thus became blurred. Even when constant use during eighteen months of trench warfare had expanded the knowledge of these weapons, the shifting conditions of tactics falsified attempts to foretell with any degree of certainty the numbers in which particular stores would be required. Over-estimation led to the accumulation of large stocks of obsolete patterns. Under-estimation brought about urgent demands at the last moment for supplies which could only be satisfactorily produced after months of systematic preparation. It was only later, when patterns had become somewhat standardised, that stability was attained by the building up of a sufficient reserve of tried and approved weapons, or by the gradual replacement of less satisfactory designs with the new and more efficient models.

The whole period between the autumn of 1914 and the spring of 1916 was marked by an opportunism which had its sole justification in the emergencies of the time. The British armies were faced on the Western and Mediterranean fronts by an enemy immensely superior in trench warfare supplies. It was realised that the provision of these should be easier and quicker than the production of guns and gun ammunition. The first aim was to acquire large quantities at once, rather than to await the slower processes involved in the normal, scientific development of a design. The armies in the field extemporised mortars, bombs and grenades from whatever material they had at hand. Supply authorities did the same on a rather more elaborate scale at home. Some serviceable patterns developed out of these improvisations; others were the independent suggestions of private individuals; others, again, were the result of systematic research following the normal lines of procedure.

Certain drawbacks were inherent in each of these three methods of evolving a new weapon. The army workshops enjoyed close contact with the actual conditions under which their products would be used, and were therefore in the best position for visualising the whole nature of the problem. On the other hand, their suggestions, put

forward through General Headquarters, acquired something of the force of a formal demand, and occasionally took a prior place over more satisfactory patterns which had meanwhile been evolved at home but had not yet come into service use. The suggestions of private individuals often emanated from manufacturers who were well acquainted with the conditions of production. The adoption of these was hampered by the psychology peculiar to the inventor. Supply in large quantities was hindered by the secretiveness of monopolists. In his desire to perfect his creation, the inventor would introduce constant changes, while at the same time he would oppose advantageous alterations emanating from some brain other than his own. Systematic research at home was a scientific process and the most likely to lead in the end to sound results; but it was necessarily slow, and there was no time to wait. Again, in aiming at perfection, it was apt to overlook the very nature of the problem, which was to produce cheap and quickly made *matériel* supplementary to, and not mere replicas of, standard ordnance.

It was not until the spring of 1916 that the need for simplicity in the design of trench warfare stores was an accepted fact. Meanwhile the Army had been supplied with considerable numbers of stopgap weapons, and with an inadequate but slowly increasing supply of safer and more efficient stores of complex design. The Battle of Loos was fought in September, 1915, entirely on emergency types of grenades and on the dangerous 3·7-in. mortar, for which alone was there ammunition in anything like significant quantities. The Mills grenade, a serviceable pattern capable of speedy reproduction, was put forward by a manufacturer in the spring of 1915, and was issued in millions late in the year.

In March, 1916, the simplification of trench mortar ammunition enabled the organisation of the preceding nine months to bear fruit. The output of simple and serviceable bombs was sufficient to meet the needs of the Army without any further reliance on the original types of complex pattern, doubtful safety or mediocre efficiency. The question of *personnel* could again be put before that of *matériel*. The Commander-in-Chief could facilitate the training of his men and simplify the use and transport of trench warfare stores by a radical reduction in the number of types. This he did in May, 1916, by abandoning all save three of the types of trench mortar and eliminating from use the percussion grenade. The numerous stopgap hand grenades had already given place to the popular and serviceable Mills grenade. The day of the emergency store thus came to an end.

The first energies of the supply authorities had been bent upon the immediate issue of these stopgap weapons, while they built up from purely commercial sources an adequate organisation for producing trench warfare stores by the million and struggled to obtain authority to make weapons simple enough to be produced in the industrial workshops of the nation. The use of this manufacturing capacity existed as a mere scheme in the minds of the officers concerned when the Trench Warfare department of the Ministry of Munitions was formed in

the summer of 1915. The new department based its whole practice and policy upon the utilisation of commercial sources alone, leaving the ordinary armament firms and the Ordnance Factories free to produce the more complicated munitions of war. It made use of numerous small workshops, and in many instances organised a system of group-manufacture, maintaining through a staff of outside engineers direct control over the various stages of production and the constant changes in process due to instability in design. High prices ruled at first, and an uneconomical system of payment on a cost plus percentage basis was temporarily necessitated by lack of knowledge of entirely novel manufacturing problems. When stocks had been built up and experience obtained, the rates of payment were reduced and standard prices introduced for the more important stores, although constant changes in design and the uncertain nature of the manufacturing programme gave contractors good reason for claiming some margin over their normal rate of profit. The few months which elapsed before the cessation of hostilities scarcely gave time enough to show whether trench warfare weapons were sufficiently standardised to dispense with the separate treatment formerly accorded to them as novel stores. Moreover, in the summer of 1918, provision was made for the design department concerned to control experimental supply through a staff drawn from the former headquarters staff of the outside engineers, thus providing for closer and more direct control in the case of those stores for trench warfare of which the design was not yet stable.

The most important of the stores produced under the circumstances described above were trench mortars and their ammunition. When the war of positions was fully established in October, 1914, the British Army had not a single mortar, nor did any service pattern exist. In response to the first formal demand for something akin to the German *minenwerfer*, the Ordnance Factory and armament firms developed various service patterns, one light and two medium. A second light pattern was evolved by the Army itself and afterwards manufactured at home. The spring offensives of 1915 intensified the need for mortars; but output of the more serviceable of these patterns was limited by the complex nature of the fuses and other difficulties in the design of the ammunition. When in July, 1915, the Ministry of Munitions became responsible for supplying these weapons, a few hundred only had been delivered in view of the difficulty of supplying ammunition. The Minister insisted upon the production of a type of light mortar which could be manufactured in large numbers, and in August, 1915, sanctioned the immediate production of one thousand Stokes mortars. Simultaneously, the new department organised among commercial firms manufacture of 1,000 medium mortars of the 2-in. type, the most efficient of those as yet evolved. This project was only carried through by an insistence upon modifications in pattern and specification to facilitate manufacture. In the autumn of 1915 Mr. Lloyd George again took personal action in borrowing from the French Government samples of a heavy mortar and arranging for its reproduction in considerable numbers. The

introduction of simply-made fuses in February, 1916, enabled the trade-made ammunition to be issued in large numbers. Manufacture by the Ordnance Factory gradually ceased. The one pattern of mortar produced by an armament firm was eliminated together with all save three standard types. Ammunition was produced in quantities which met, and sometimes exceeded, the demands of the Army. The total numbers manufactured by the end of the war included eleven and a half millions of light (3-in. Stokes) bombs, over quarter of a million heavy bombs, and three and three-quarter millions of medium bombs of either the 2-in. pattern or the more efficient 6-in., which replaced it during 1917-18. The last two years of the war were chiefly marked by improvements in the design of each of the three classes and notably by important increases in their range.

The position in respect to grenades was slightly more satisfactory at the inception of trench warfare. Service patterns of hand and rifle grenades existed, but they were of such complex design that it was impracticable to make them in large numbers. Moreover, the secretiveness of the monopolist in one instance prevented any immediate expansion in the capacity for manufacture. The introduction of the Mills type provided a satisfactory hand grenade, output of which reached its zenith by the end of 1916. Rifle grenades lagged behind, delayed by the complexity of the pattern; but the production of these had almost met the formal demand by this same date, when it was ascertained that expenditure had been over-estimated, and in consequence supply of both hand and rifle grenades was slowed down for the time. In 1917 a new type of combined hand and rifle grenade was introduced, evolved from the Mills time-fused hand grenade. In the spring of 1918 this pattern was further developed for firing from a rifle by means of a discharger cup, a method dispensing with the cumbersome rod previously used. The older type of percussion rifle grenade had been developed alongside the Mills pattern, and was finally replaced in 1918 by a safer and more efficient type of rifle percussion grenade. Percussion grenades for hand use had been abandoned in the spring of 1916 in accordance with the policy of reducing types. Although much research was subsequently expended upon producing a satisfactory form of percussion grenade for use with the rifle or by hand, none had been brought into service use by the end of the war. In spite of the difficulties due to constant fluctuations in the demand, enormous quantities of grenades were produced, output of the Mills grenade alone reaching seventy-five millions before the cessation of hostilities.

In addition to these two main classes of stores, several miscellaneous weapons and appliances were produced for special purposes in connection with trench warfare. The mortar was for some months supplemented by mechanical bomb engines, catapults and spring guns, which were abandoned as soon as the safer and more efficient types of mortar became available in large numbers. The first stages of chemical warfare were closely connected with trench warfare. Irritant and lachrymatory grenades were issued in 1915. A special form of

the Stokes mortar (the 4-in.) was evolved for use with smoke bombs to act as part of the smoke screen used for the attack at Loos in September, 1915, and the mortar of this calibre was retained in service use chiefly as a means of projecting lethal mixtures until the close of the war. Again, from the flame-projectors provided and used in comparatively small numbers during 1915 and 1916 sprang the Livens projector introduced into the service in 1917 for the creation of gas clouds. This weapon possessed in a remarkable degree the simplicity and cheapness which characterised all trench warfare stores. The rapidity with which its production on a large scale was developed was partly due to this fact and partly to the peculiarly intimate relations which existed between the authorities concerned in the development of its design, the organisation for its production, and in its introduction and use in the field.

The most notable of the miscellaneous stores provided for the purposes of trench warfare were the steel helmets, for which a demand was first made in the August of 1915. The next six months were occupied in overcoming the problem of manufacture on the huge scale needed for the equipment of the entire army. In particular, it was necessary to evolve processes for making and stamping the special high-grade steel upon which military authorities insisted. The efficiency of the helmets supplied was abundantly proved in March, 1916, and the first million out of the seven million produced during the war was completed by the following July.

In conclusion, it should be noted that the novelty of trench warfare stores rendered them peculiarly sensitive to the conflicting forces of efficiency and safety and rapidity of production. These were reflected in a certain degree of controversy between the Army, the design officer and the supply authority, which gave to many changes in the administrative organisation an importance which would not otherwise be theirs. A compromise was usually reached by accepting for immediate use patterns in which the factors of safety and efficiency were comparatively low and by subsequently replacing them with more satisfactory types evolved along scientific lines and manufactured in bulk by means of systematically organised methods of supply.

APPENDICES.

APPENDIX I.

(CHAPTER III., p. 41.)

Position of Trench Mortars, 25 July, 1915.[1]

Makers.	Bore.	Weight of Gun and Carriage.	Type of Shell.	Weight of Shell.	Bursting Charge.	Firing Charge.	Fuse.	Range.	Number Delivered to Date.	Number in Use and to be Used.	Number on Order.	Date of Delivery.	Notes.
Woolwich	2-in.	lb. 260	C.I. stick bomb	lb. 50	lb. 17 40/60 amatol	3½ oz. cordite	No. 27 Mk. I No. 65a (modified) No. 80	yds. 500	25	20	50 Woolwich, 100 to be ordered from trade as soon as possible.	18 p.w.	Very effective in range and shell, but has two or three serious defects to be put right before order is finally placed with outside firms.
Woolwich	3·7-in. Mk. III	50	Tin pot	4½	1 T.N.T.	Guncotton 3 dhms.	Bickford	340	110 in France from Woolwich. 20 in Dardanelles. 100 more on order, Woolwich, started 20 July.		—	—	Considered in France a very unsatisfactory gun, exceedingly dangerous to operators, and no more of this type will be made.
Woolwich	4-in. (rifled) Mk III	110	Pressed metal case	8½ with studs	3½ T.N.T.	Guncotton	No. 65a	900	20 in France. 8 just despatched (20 July). 2 will be delivered 24 July.		—	—	A fairly accurate gun, and capable of long range with a small shell, slow loading, and rather expensive shell case.
Vickers Type 1	1·57-in.	200	C.I. stick bomb	18	2·75 Permite Pdr.	540 gns. M.D. Cordite	Special time fuse.	325, now increased to 505	50 more on order from 20 July.		—	To begin 3 weeks hence.	These guns are very heavy and clumsy to move, but shoot fairly accurately, and are fairly satisfactory.
Type 2	1·57-in.	200	C.I. stick bomb	33	2·75 Permite Pdr.	540 gns. M.D. Cordite	Special time fuse.	207, now increased to 290	140	140	10	25 July	

[1] Reported by Lieut. Sutton as the result of a visit to France (HIST. REC./H/1610/8).

APPENDIX II.

(CHAPTER III., p. 46.)

War Office Requirements of Trench Howitzers and Ammunition, 11 November, 1915.[1]

Nature.	Guns in Possession or under Order.	Guns Required in Addition.	Total.		Requirements on Certain Dates of Guns and Ammunition. 1 Dec.	1 Feb.	1 April.
Light—							
4-pdr... ..	320	500	820		400	600	820
				Ammunition p.w.	37,800	47,250	60,270
4-in. O.F. ..	62	238	300		80	160	300
				Ammunition p.w.	6,300	12,600	19,250
Stokes 3-in. ..	800	480	1,280		800	1,000	1,280
				Ammunition p.w.	63,000	73,500	94,080
Medium—							
1·57-in. ..	200	75	275		230	250	275
				Ammunition p.w.	11,550	13,125	14,440[2]
2-in.	925	—	925		400	600	925
				Ammunition p.w.	21,000	31,500	45,325
Heavy—							
	—	400	400		—	200	200[3]
				Ammunition p.w.	—	13,720[4]	27,440[5]

[1] Forwarded under covering letter, 11 November, 1915 (D.M.R.S. 262).
[2] Added later in pencil and queried.
[3] Altered later to 400.
[4] Altered later to 7,357.
[5] Altered later to 13,720.

APPENDIX III.

(CHAPTER II., p. 19.)

Co-operative Manufacture of Naval Mine Supplies.[1]

In the spring of 1917 the development of the submarine campaign resulted in a very large increase in the Admiralty's mine programme, and the restriction of tonnage brought about a considerable reduction in the Ministry's shell programme. Accordingly, between the months of February and May, various schemes were set on foot for utilising for the production of naval mines the spare capacity administered by the Ministry of Munitions. A plan for using the national projectile factories was eventually abandoned, since very little of the plant was found to be suitable for mine supplies.

The revision of the manufacturing programme for shell, which took place towards the end of May, again fully occupied the capacity of these factories. Their contribution to the output of mines was therefore restricted to supplying certain drop-forgings, pressings and small parts of the Mark VIII sinker. The only shell-contractor transferred was the North British Locomotive Company, who in July, 1917, undertook to weld and assemble 6,000 mines, supplying the necessary pressings. A certain amount of mine filling was allocated to the gun ammunition filling factories. A greater measure of assistance was given by the Trench Warfare Supply department of the Ministry in organising and administering the manufacture of mines and sinkers by numerous small firms, each of which undertook certain parts, while the final assembling was effected at central factories.

The first request, formulated by the Admiralty on 9 March, 1917, was for 15,000 sinkers Mark VIII, 14,000 sinkers Mark XII, 50,000 H.2 mines and 320,000 horns and batteries. These numbers were subsequently modified. In particular the demand for Mark VIII sinkers was increased to 19,000 on 1 April with a view to facilitating supply, and a slight reduction was made in the number of horns and batteries to be ordered. On 3 May it was agreed that the Ministry should become responsible for the entire future supply of Mark VIII and Mark XII sinkers, H.2 mines and horns and batteries, in order to eliminate any possibility of competition between the two Departments. Shortly afterwards it became apparent that the capacity which could be spared from shell manufacture would be much less than had been anticipated. During the summer an administrative reorganisation at the Admiralty brought into existence a specialised production department, and responsibility for the supply of mines was transferred to the new Deputy Controller of Armament Production, Sir Vincent Raven. It was then impracticable to transfer

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[1] Based on HIST. REC./H/1600/6; HIST. REC./R/1680/4.

bodily to the Admiralty the organisation for mine-supplies which had already been set up by the Trench Warfare Supply department, since it consisted not only of a separate unit at headquarters under Lieutenant L. G. Shadbolt, R.N.V.R., but also of the outside engineers of the department. These were employed in common in connection with all the munitions administered by the Trench Warfare Supply department, and upon their activities the success of the co-operative system largely depended. It was therefore decided in conference on 17 July, 1917, that the group organisation should remain under this department, occupying towards the Deputy Controller of Armament Production the position of a contractor.

All questions of design were settled by the naval authorities, modifications to facilitate supply being discussed in conference between the officers concerned. The trench warfare outside engineers tested materials along lines laid down by the Admiralty; provisional examination of parts was carried out during manufacture by the Admiralty area inspectors; final inspection was undertaken by the Admiralty at the assembling centres. Inspection and shop gauges were obtained through the gauge department of the Ministry both for Admiralty and trench warfare contracts. The supply of these had originally been a limiting factor in output under the Admiralty; but this difficulty was overcome in the summer of 1917, in particular by the establishment of a new source of supply for the horn and battery screw-gauge at Paisley.

The group system was adopted by the Trench Warfare Supply department as a means of lowering the cost of production and in view of difficulties experienced in placing the first contracts for Mark VIII sinkers. Nearly all the available firms were already engaged upon Admiralty orders or were sub-contracting to Admiralty contractors. By 19 May, 1917, nine firms had undertaken 4,500 complete sinkers only towards the 19,000 first required. The contract price ranged between £40 and £43 per sinker.

The group system was therefore adopted for the remaining 14,500 of this demand, the intention being to utilise special capacity for special work, to use unskilled labour as much as possible and to economise plant. Certain preliminary steps were necessary and occupied some time. The design was subjected to certain modifications. The drawings were dissected into groups, each of which involved a specific class of work. Numerous jigs were made and issued to contractors in order to ensure the interchangeability of the various units. Contractors sent samples of their work to the assembling station for careful examination and report. For this first supply orders were divided into twelve main groups, of which the first seven were the most important, and the remainder consisted of small items readily obtained. In addition, a much more elaborate sub-division was made of many of the smaller items, such as drop forgings, turned parts and pressings. These were obtained by the department in large numbers from comparatively few firms and were supplied by the department to the contractors. The cost of these

"central source" items was thus reduced, competition between group contractors in obtaining them was eliminated, and the danger of any shortage was avoided.

The assembling of the parts of the Mark VIII sinker consisted of a series of mechanical operations. A central assembling station was established at the works of the W. R. Morris Motors, Ltd., Cowley, near Oxford. The premises were taken over under a rental agreement as from 2 April, 1917, and their equipment was completed by the end of July. The department became responsible for all outgoings, the actual management of the station remaining with Mr. Morris at a fixed salary. The groups were moved forward to the assembly station on issue warrants prepared by the department to meet requisitions made by the assembling station. Abundant storage capacity existed at the station for nearly every item. A system of daily stock records formed the basis of communication between the department, the outside engineers and the contractors. It was the duty of the engineers to secure the close control of the department over the numerous contractors in order to ensure co-ordination in the manufacture of the different groups. They expedited work. They advised the group manufacturers in their areas, being themselves kept informed of defects leading to rejections at the central station by means of a weekly report. They aided the correct allocation of "central source" items, and they tested the raw materials at works.

In most respects the system established for the first supply of Mark VIII sinkers worked satisfactorily. Output began at the end of August and rose steadily to 750 weekly by 12 October. The total capital expenditure upon the assembling station was eventually £21,619. The cost of production was considerably less than that of the contract price for complete sinkers, amounting in all to £35 8s. per sinker.[1]

Experience, however, revealed the need for certain modifications which were introduced in dealing with a second demand for 23,000 Mark VIII sinkers, received on 21 April, 1917. The initial work of assembling had been delayed by shortage of two groups; the arrangement of groups was considerably altered in order to make better use of the capacity of each firm and to avoid sub-contracting. The work was reorganised in 18 groups, each of which was limited to a particular class of work. One item only (the dashpot) combined gun-metal

[1] This allowed for headquarter charges and capital expenditure as follows:—

	£	s.	d.
Average cost per 12 groups	£31	12	0
Cost of assembling per sinker	1	9	0
Carriage of parts to assembling station	1	1	0
Grease and painting		1	0
Capital expenditure on assembling station and jigs, allowing for writing off the entire capital expenditure on the 44,500 sinkers made on group system for the first three demands		15	0
Departmental establishment charges		10	0
TOTAL	£35	8	0

and steel work and sub-contracting was allowed in this instance. Delay had been ascribed to the late establishment of central sources for small parts; these sources were set up for the second demand before the main orders were placed, and one area, Glasgow, set up its own source of supply. The capacity of the assembling station in August, 1917, was 1,500 weekly, but the inspection arrangements were insufficient for this number; they were therefore extended. The drawings and specifications to meet the second demand were available in June. All orders had been placed by 25 August. The first deliveries on this requirement were made in the last week of October. The whole number was produced under the group system.

A third demand for 9,000 Mark VIII sinkers received on 23 September, 1917, was met by placing contracts for 7,500 under the modified grouping and ordering the balance from the original contractors for the complete article in order to maintain their capacity. These continuation orders for complete sinkers were placed at £34 per sinker; the unit of cost on the group system had been reduced under the modified grouping to £28 3s.

The original demand of March, 1917, included 50,000 H.2 mines, of which it was then estimated that 18,000 could be produced by spare shell capacity; but this number was subsequently reduced to the 6,000 made by the North British Locomotive Company. The remainder were provided by the Trench Warfare Supply department on a group system similar to that used for the Mark VIII sinker. The chief difficulty was experienced in obtaining the large hemispherical pressings and in providing the welding capacity for assembling the parts. Most of the pressings were obtained from railway shops. Quasi-arc welding was adopted as far as possible in view of the shortage of oxygen and the satisfactory results already achieved with this method in producing 9·45-in. trench mortar bombs. A large proportion of the capacity for bombs of this nature was converted into mine assembling stations, two contractors undertook this work under assisted contracts, a third had the necessary plant available, and the Eastbourne Corporation equipped an assembling station at their own expense. The main points in the design of this mine were settled by the end of June, 1917. Components began to come forward to the assembly stations towards the end of August, but assembling was delayed during the next two months by a change in design, the completion of jigs and the organisation of a somewhat complex system of testing. Output in number began in mid-November, and reached 640 weekly by 7 December and 1,000 weekly at the end of the next fortnight.

The group system was thus applied to two stores, the Mark VIII sinker and the H.2 mine. The remaining mine-supplies produced by the department were obtained by the normal method of contract for the complete article, the services of the outside engineers being utilised in the finding of capacity and the general hastening of contracts. The original demand of March, 1917, included 14,000 Mark XII sinkers.

These were of a simpler pattern and were eventually produced as complete articles by the large cotton machinists in the Manchester district. Preliminary arrangements as to the design and specification were settled by 22 June. All orders were placed early in July. Continuation orders were given to meet a second demand received on 23 September. First deliveries had come forward at the end of August and by mid-October output reached 650 weekly. During the next three weeks it rose to 1,200, at which number it was maintained.

The production of the 300,000 horns and batteries presented a comparatively simple problem. Initial questions of design were settled by 8 June, 1917. Difficulty in obtaining screw-gauges was overcome by the establishment of a new source of supply. The use of a concentric gauge was abandoned when it was found to be limiting output. Preliminary difficulties were overcome by 1 September and deliveries reached 5,200 weekly by 21 September and were subsequently maintained 7,000 a week.

Thus by the end of 1917 the production of mine supplies was fully organised under the Trench Warfare Supply department and output was maintained to meet the Admiralty requirements. Additional demands for each of the mine supplies so produced were formulated on 4 February, 1918 ; but an all round 40 per cent. reduction in output was required on 15 April. Upon this it was suggested by the Trench Warfare Supply department that its efforts should be concentrated upon the two stores which were being obtained by the group system. At the time, this department was being absorbed piecemeal into the main body of the Ministry of Munitions. Under the circumstances it was decided in May, 1918, to transfer to the Admiralty the department's organisation for dealing with mine supplies.

Arrangements were accordingly made for the Deputy Controller of Armament Production to take over the section administering these stores, which became the "Mines Group Section" of the Admiralty. It was considered important to retain the group system in view of the satisfactory results obtained and the fact that production was effected under it at rates considerably lower than the contract prices paid by the Admiralty. This success was attributed not only to the group system but also to the administrative procedure of the section, which gave to the supply officer complete control over the administration of contracts. He undertook all negotiations and correspondence with contractors, and issued drawings and specifications. The work of the finance and contracts officers was thus limited to consideration of purely financial arrangements and the preparation of the formal contracts documents. Some difficulty was experienced in adapting this procedure to the administrative arrangements of Admiralty. The duties of the supply department under the Deputy Controller of Armament Production were restricted to making recommendations as to the firms to be invited to tender and to forming a link between the contractor on the one hand and the design, inspection and contract branches on the other. Under this system the administration of contracts

remained almost entirely in the hands of the Contracts Branch. Yet, as concerned the new Mines Group Section, it was desirable to maintain as far as possible the arrangements already established in administering the group system, since the number of contractors involved was so large. It was eventually settled in September, 1918, that the Mines Group Section should conduct all negotiations and correspondence with contractors; that where possible maximum prices should be fixed beforehand between the Deputy Controller of Armament Production and the Director of Navy Contracts. Otherwise prices should be settled provisionally, subject to the Director of Contract's concurrence. A representative of the Director of Contracts was to be attached to the section, to be kept informed of all negotiations and to be present when prices were discussed. The actual signature of contracts was to be carried out daily by the Director of Contracts.

The only orders actually placed under these conditions were intended to meet a demand for 8,000 Mark VIII sinkers made in September, 1915. So far as could be judged the procedure worked smoothly and satisfactorily during the short period preceding the Armistice. For the purpose of liquidating the contracts, most of which had been placed by the Ministry of Munitions, the section was re-transferred to the Ministry at the end of the year. When manufacture ceased the total deliveries made under this section were as follows :—

	Total Demand.	*Total Deliveries.*
Mark VIII sinkers	65,000	52,403
H.2 Mines	74,000	49,337
Mark XII sinkers	23,000	23,000
Horns and batteries	444,000	439,800[1]

[1] To the week ending 21 February, 1919. The balance to be taken by the Admiralty as produced.

APPENDIX IV.

(Chapter II., p. 31.)

Beddington Box Repairing Factory.

Cement stores at Beddington, co. Surrey, were taken by the Minister of Munitions under a rental agreement terminable six months after the cessation of hostilities or upon three months' notice from the Minister. Work upon the conversion of the premises began at the end of November, 1916. Labour-saving devices were installed and the equipment of the factory was completed by the first week in February, 1917. Certain structural alterations were afterwards effected in order to expedite output.

The factory was controlled directly by the Trench Warfare Supply department for repairing salvable grenade and bomb boxes, which were re-issued to contractors in the neighbourhood. Operations began towards the end of December, 1916. In April, 1917, a system of record keeping was organised with a view to standardising the workers' efficiency. In the following June a revision in the specification for grenade boxes increased the output, which was originally 12,000 boxes weekly, and by September, 1917, had reached 15,000 weekly. Much space, time and labour were saved by the adoption in February, 1917, of a system of inspection while the boxes were being rectified. Practically all the workers were women who were engaged in loading and unloading as well as in repairing and painting the boxes. The original cost of 10d. per box was halved by April, 1917. This saving was effected by the use of machinery and by improvements in the methods of work. The total expenditure on land and buildings, plant and machinery, down to March, 1918, amounted to £7,211.

APPENDIX V.

(CHAPTER II., p. 24.)

Trench Warfare Filling Factory, Denaby.

A factory for filling 3-in. Stokes bombs was built on a seven-acre site adjacent to the ammonal factory of the British Westfalite Company at Denaby, near Rotherham, co. Yorks. The land was leasehold of the Company and the buildings were erected at Government cost to plans agreed between the company and the department, the actual orders being placed by the company's representative. Constructional work began about the middle of August, 1915, and the original buildings, except certain storage sheds and a changing room, were completed by mid-February, 1916. Additional land was taken up in the following March to meet the extended Stokes bomb programme, and the new buildings, consisting of ten filling sheds, were completed by the following July.

The method of administration was under discussion between the department and the Company between August and December, 1915. The contract price asked per box of three bombs was at first 3s. 6d., afterwards 1s. 9d. From 1 January, 1916, the factory was nationalised under an agency agreement, the company accepting £250 to cover all supervisory duties up to that date. Under the final agreement, which was dated 24 May, 1916, and was retrospective, the company undertook to fill 3-in. Stokes bombs at a fixed yearly fee and a bonus of £1 per thousand bombs satisfactorily filled. The Minister defrayed the cost of production including labour, light, heat, transport and material except the explosive, which was charged to the agents at a fixed rate. The buildings and equipment were to be the property of the State until twelve months after the termination of the war or the determination of the contract, whichever should be the later. The agreement was thus very similar to that for agency shell filling factories; but an important variation was introduced at the instance of the Company, whereby the Minister indemnified them, not only against loss by fire or under the Employers' Liability and Workmen's Compensation Acts, but also against loss of profit and damage at their adjacent explosive factory arising out of any accident at the national factory. The labour was controlled by the agents, but the Minister had power to dismiss workers or vary the rate of wages, and a technical representative of the department was resident at the factory.

The factory was laid out to fill 75,000 bombs weekly, serving as a centre for the empty bombs made in the northern counties. In January, 1917, a clearing house for these shells was established at Rotherham to prevent congestion at the factory, where they were

loaded and packed into boxes with their components ready for direct issue overseas. Filling began in small quantities on 11 December, 1915; on a large scale, 29 January, 1916. In June, 1916, work was stopped temporarily on account of congestion due to lack of delivery instructions. In the following August it was decreased by half, special arrangements in reducing hours of work being made to enable the maximum output to be re-established. This was done in the following August, and in the spring of 1917 a weekly output of 90,000 was reached without introducing night shifts. At this time this factory was the sole source of supply for bombs of this nature. In April, 1917, work was entirely suspended for a few days during a change-over in the design of bomb. It was subsequently partly occupied in disassembling obsolete 3·7-in. trench mortar bombs. Filling of 3-in. Stokes bombs was gradually resumed in June, 1917, and output rose to 110,000 weekly by the end of August. Arrangements were then made to increase the capacity still further in order to fill bombs for the Allies. This was done without incurring additional capital expenditure and the factory continued loading 3-in. Stokes bombs until the termination of hostilities.

Several improvements in methods of filling originated in this factory. Early in 1916 a new steel drift was introduced, and in January, 1917, a novel pattern of filling bench was installed which reduced the loose ammonal to a minimum. The filling was done entirely by hand. The weekly average of workers employed during 1916 was 359, during 1917, 405. By far the greater number were women, and in May, 1917, the transport arrangements were reorganised to enable 27 men to be replaced by women.

Denaby was regarded by the department as among the most successful of the factories under its control, both in economy and efficiency. The capital expenditure was estimated in February, 1916, at £6,000, in December, 1917, at £13,066. The actual expenditure down to 31 March, 1918, was £14,710.

APPENDIX VI.

(CHAPTER II., p. 24.)

Trench Warfare Filling Factory, Erith.

The Erith factory for filling 2-in. trench mortar bombs was built on grazing land adjacent to the Thames Ammunition Works on the Crayford Marshes. It covered an area of 14 acres and was two miles from Slades Green Station, from which a siding was laid. The buildings were partly adapted from packing sheds and magazines belonging to the Thames Ammunition Works, partly erected at State cost. The filling station proper was on leasehold land of that company; the receiving and distributing sheds were on the adjacent leasehold of an interned Austrian, which was taken under the Defence of the Realm Act. Instructions were given to the Thames Ammunition Company for the erection of the factory on 21 August, 1915, and the filling sheds were completed by the end of the following January. There were eighteen sheds in all.

An agreement with the Thames Ammunition Works for operating the factory was under discussion between August, 1915, and the following January. The alternatives proposed were :—(1) The Minister to rent the site and bear the cost of construction, the contractor filling the bombs at a flat rate and paying a nominal rent for the buildings; or (2) the firm to fill on a cost plus percentage basis; or (3) (suggested in December, 1915) an agency agreement similar to the Denaby agreement and to cover filling operations only, the receiving and distributing station to be directly controlled by the department. From 27 January, 1916, the factory was taken over under the Defence of the Realm Act, owing to the failure to come to reasonable terms with the contractor and the receipt of adverse reports on the general conditions, particularly as regarded danger regulations and female labour.

Throughout the war the factory was engaged in filling ammunition for the standard medium mortar. Work on 2-in. bombs began in the week ending 2 October, 1915. In the following January the factory undertook the entire filling programme for this nature. It was originally laid out for 20,000 bombs weekly and was extended to deal with 25,000 in April, 1917, when output had already exceeded 20,000 owing to the high efficiency attained. In May, 1917, the lay-out was reorganised for filling 6-in. trench mortar bombs instead of 2-in., the filling of which was entirely transferred to Watford No. 1 in the September following. Gravity conveyors were installed for handling the heavier 6-in. bombs. Filling of this nature began at the end of May, 1917, and continued until the termination of hostilities. The

total output of 2-in. bombs was 1,142,806, and of 6-in. bombs 1,063,193. It was decided in June, 1917, that no further extensions would be practicable in view of the difficulty in obtaining labour.

The district was sparsely inhabited and labour only available from a distance and in competition with many other munition works. Workers were brought by motor transport and later by rail when the siding was completed. Canteens provided breakfast, dinner and tea. The average weekly number of employees in 1916 was 350; in 1917, 400. Five-sixths were women, the remaining sixth, men. A flat time-rate was paid with a bonus on the quantity filled. The high piece-rates at Woolwich drew away considerable numbers, so that the whole *personnel* of the factory was changed about once in three months.

The capital expenditure was estimated at £24,000 in February, 1916, at £35,042 in December, 1917. The actual expenditure down to 31 March, 1918, was £42,041.

APPENDIX VII.

(CHAPTER II., p. 25.)

Trench Warfare Filling Factory, Fulham.

In August, 1915, W. E. Blake, building contractor, agreed to erect a factory for grenade filling. He formed a special company, the W. E. Blake Explosives Loading Company, for the purpose, and built the factory on three acres of waste ground at Stevenage Road, Fulham, on the south bank of the Thames, obtaining a lease of the site from the Ecclesiastical Commissioners. It was adjacent to Mr. Blake's grenade factory and lay in the midst of a very crowded district. The magazines were established at a distance on disused playing fields at Worm Holt Farm, Shepherd's Bush. Transport was organised by barge to Deptford and thence by rail to Newhaven.

The factory was originally built for loading 80,000 Ball grenades weekly, and the filling of Ball, Mills, and other types of grenades was carried on under contract until January, 1916. A scheme for converting the factory to a station for filling 3-in. Stokes ammunition was initiated in October, 1915, and experimental work on these bombs began on 21 October. In the following December negotiations with the contractor for continuing bomb-filling under an agency agreement fell through. Shortly afterwards adverse reports were received as to safety conditions and accommodation for workers. In view of these facts and the failure to come to reasonable terms the factory was nationalised under the Defence of the Realm Act as from 11 February, 1916. By that date grenade-filling had been transferred elsewhere. During February and March the factory was reconstructed and reorganised, and was the first to load 100,000 3-in. Stokes bombs in a single week. In June, 1916, this work was reduced to 50,000 weekly owing to the accumulation of filled bombs. In the September following it was again decreased to 23,000 weekly, and from January, 1917, the loading of these bombs was gradually transferred to Denaby.

The factory began pyrotechnic work in June, 1916, with the filling of flares. By the following January a record standard of efficiency had been reached, and the first 1,110,000 were completed by 24 February, 1917, when work began on another million. These were finished by the end of March. Plant for filling and assembling Véry signal cartridges was installed in April, 1917; output began within three weeks, and by mid-June experiments had led to the improvement of manufacturing methods with a corresponding increase in production.

Grenade filling began again in November, 1916, and eventually became the leading work of the factory. Pneumatic apparatus was

invented for filling Mills grenades and the plant installed in December, 1916, reducing the labour employed on this work by 90 per cent. and the cost by £2 per 1,000. This machine enabled a single girl worker to obtain a record of 6,000 grenades filled in a nine-hour day. Grenade-filling continued until the Armistice, six different kinds being handled while the factory was under national control.

Miscellaneous work upon minor components began with the filling of Stokes propellant rings in August, 1916, and the assembling of Midgeley fuses for aerial bombs in November, 1916. The factory also undertook a considerable amount of experiment, such as the filling of bombs and grenades with amatol to test its suitability in these stores and the adaptation of the 3-in. Stokes bomb for incendiary purposes. The introduction of economical methods at Fulham enabled contract prices to be reduced. Thus, a comparison of costs in the manufacture of cordite rings enabled flat rates to be established with a saving of £2 10s. per 1,000. The miscellaneous character of the work is illustrated by a week's output in September, 1918, which included three types of grenade, five of pyrotechnics, experimental bomb-filling, the manufacture of cordite rings, quick-match and ignition papers and the breaking down of charges.

The local labour supply was ample and day shifts only were worked. The proportion of women to men was 15 to one. A flat rate was always paid. The average number employed weekly in 1916 was 485, in 1917 462, and in 1918 it was still below 500. A canteen was opened under arrangement with the Central Control Board in May, 1916.

The estimated capital expenditure in December, 1917, was £16,860. The actual expenditure down to 31 March, 1918, was £19,684, being limited to the lowest amount possible in view of the temporary character of the factory.

APPENDIX VIII.

(CHAPTER II., p. 24.)

Trench Warfare Filling Factory, Watford No. 1.

This factory was built on 20 acres of agricultural land at Balmoral Road, about two miles from Watford Junction. It was adjacent to the national factory for the manufacture of ammonal, erected at Watford by the Explosives Supply department. It occupied part of the site taken over under the Defence of the Realm Act for that factory. The project for the filling factory dated from 3 September, 1915. The lay-out was partly based on the Woolwich and Erith bomb-filling shops; the buildings were necessarily scattered, owing to the existence of a "pot-hole" in the middle of the site. General authority for the expenditure was obtained by the Trench Warfare department about 4 October, 1915. The original buildings, consisting of about 19 sheds, were completed by the second week in February, 1916. From the first the factory was directly controlled by the department, and was managed by a superintendent, a volunteer, who afterwards took responsibility also for Watford Factory No. 2.

The factory was intended to load 2-in. trench howitzer bombs with ammonal from the neighbouring explosives factory, and to pack the filled bombs with their components for issue overseas. Work began on 16 October, 1915, with the filling of 3-in. Stokes bombs, which was undertaken temporarily, and ceased on 8 January, 1916. The maximum output of 2-in. bombs obtained was 20,000 weekly. The filling of this nature began 20 December, 1915, and continued until the second week of January, 1917. It was then suspended for seven months, during which 2-in. bombs were filled at Erith only. It recommenced on 7 July, 1917, and from the end of the following September all 2-in. ammunition was filled here until the change over to 6-in. bombs took place at the end of the year. The examination and assembling of fuses began in the second week of March, 1916, and new assembling rooms were completed for this purpose early in May. From April, 1916, till the following August the filling of first deliveries of 9·45-in. bombs was undertaken, pending the construction of Watford No. 2 Factory. Work on assembling chemical, incendiary, and smoke bombs began with experimental lots of 4-in. Stokes bombs in the second week of May, 1916, and reached a commercial scale at the end of July. In July, 1916, special sheds, partitioned by hempen rope mantlets, were erected for the particularly dangerous operations of filling ophorite gaines for chemical bombs, and filling 2-in. bombs with thermit. Additions were made to these sheds during the first six months of 1917, when the greater part of the capacity of

the factory was concentrated upon these operations. Some work was also done in filling the exploders of 6-in. artillery shells filled with chemicals. In January, 1917, the factory began assembling components for the 9·45-in. ammunition, and in the following April it undertook the entire assembling of components for 3-in. Stokes bombs made in the London district.

The total number employed in November, 1915, was 39, of whom 22 were men. In 1916 the weekly average of employees was 360, in 1917, 450. Originally these were drawn from the surrounding districts, in competition with the other industries of Hertfordshire and Middlesex. Dilution eased the situation in 1916 and 1917. By the end of 1916 the women employed were 236 and men 110, and in the following March women replaced men on trolley work. Canteens, clubs, and a crèche were organised for the two factories. In the spring of 1917 the female labour of the district was exhausted, and railway fares up to 3s. weekly were allowed to overseers from outlying districts. In September, 1917, workers were brought in from Norwich. The establishment of the Greenford chemical shell factory drew away workers, and in March, 1918, the number of employees at both factories was only 30 per cent. of that needed. The situation was again met by importing labour from the provinces.

The expenditure on the original buildings was estimated in February, 1916, at £15,000. By the end of 1917 the estimate was raised to £40,487, and the actual outlay on land, buildings and plant, down to 31 March, 1918, was £40,306.

APPENDIX IX.

(CHAPTER II., p. 26.)

Trench Warfare Filling Factory, Watford No. 2.

This factory was built for filling heavy trench mortar ammunition early in 1916. It occupied about 40 acres of agricultural land, taken under the Defence of the Realm Act, at "Callowland," Bushey Mill Lane, Watford. Sites had previously been examined at the Sabulite Factory, Ware, and at Reading. A preliminary scheme for transporting the explosive direct from the Watford ammonal factory was abandoned, in view of its cost, in favour of an extension of the sidings at Watford No. 1. When an amatol bursting charge was substituted for ammonal, it was still arranged that mixing should take place at the explosives factory and not at the place of filling, as was the normal arrangement in shell-filling factories.

Constructional work was carried out under the Office of Works, by contract on a lump sum basis. The site was surveyed on 22 January, 1916, building began on 19 February, and 26 filling sheds were finished by the end of March. The completion of water supply and sanitary arrangements was delayed till June. A magazine, with a capacity of 250 to 300 tons, was built in that month.

The factory was controlled directly by the Trench Warfare Supply department, and was under the same management as Watford No. 1 (*q.v.*). It was laid out for filling 20,000 bombs weekly, and in April, 1917, was extended to deal with 25,000. Since the filling programme for 9·45-in. bombs never reached the number anticipated the capacity of the factory was otherwise occupied. In addition to undertaking the entire 9·45-in. filling programme, upon which work began at the end of May, 1916, the factory filled and assembled trench mortar fuses from June, 1916, onwards, and also fermanganised the cast-iron fuse-bodies upon special plant, completed in October, 1916. The assembling of aerial bombs began in mid-June, 1916, and in the following January the actual filling of these bombs was undertaken. In April, 1917, a scheme was started for assembling chemical artillery shell, in order to avoid erecting a special building for the purpose. The factory concentrated upon this work during a period of urgency in the early summer of 1917, but these operations ceased with the erection of the Greenford Chemical Shell Factory. From March, 1917, onwards gaines for the Livens projector drums were filled in large quantities, both for British and American use. The loading of Pippin rifle grenades began in the following May, 1917, and about 340,000 of these were filled here. In May, 1917, the work of the factory was reduced by 50 per cent., pending a decision as to its continued use for assembling chemical shell. Almost every class of work undertaken was again increased in the following July.

The labour conditions resembled those at Watford No. 1 (*q.v.*). The capital expenditure was estimated in February, 1916, at £65,000; in December, 1917, at £86,965. The actual capital cost, including land, buildings and plant, down to 31 March, 1918, was £99,050.

APPENDIX X.

The Output of Trench

	1914.		1915.				1916	
	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.
TRENCH MORTARS.								
Light—								
3 in. Stokes mortar	—	—	—	—	—	304[2]	391	1,425
3·7 in. M.L. trench howitzer	—	—	51	69	40	60	250	177
4 in. M.L. trench howitzer ..	—	12	6	22	22	—	143	95
Medium—								
1·57 in. trench howitzer ..	—	—	16	111	23	49	21	47
2 in. trench howitzer ..	—	—	2[3]	23	36	111	540	156
6 in. Newton trench howitzer	—	—	—	—	—	—	—	—
Heavy—								
9·45 in. trench howitzer I. ..	—	—	—	—	—	—	—	76
9·45 in. trench howitzer II.	—	—	—	—	—	—	—	—
9·45 in. trench howitzer III.	—	—	—	—	—	—	—	—
9·45 in. trench howitzer IV.	—	—	—	—	—	—	—	—
TOTAL	—	12	75	225	121	524	1,345	1,976
SPECIAL WEAPONS.								
4 in. Stokes mortar	—	—	—	—	31[4]	—	80	202
Livens projector	—	—	—	—	—	—	—	—

[1] The figures denote acceptances after proof.
[2] 200 of these were issued to Training Centres in November, 1915.

APPENDIX XI.

The Output of Trench

	1914.		1915.				1916	
	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.
H.E. AMMUNITION.								
Light—								
4 in. O.F.	—	545	1,020	1,574	1,860	2,368	720	14,381
3·7 in.	—	—	7,046	37,000[2]	133,032[3]	97,148[2]	283,050	353,600
3 in. (Stokes)	—	—	—	—	—	35,000[4]	805,975	1,458,285
Medium—								
1·57 in. (18 lb.)	—	—	490	2,452	25,164	8,642	8,580	10,540
1·57 in. (33 lb.)	—	—	210	872	14,790	2,420	28,900	31,720
2 in.	—	—	50	855	1,939	37,302	259,194	306,797
6 in.	—	—	—	—	—	—	—	—
Heavy—								
9·45 in.	—	—	—	—	—	—	—	10,023
TOTAL	—	545	8,816	42,753[2]	176,785[3]	182,880[2] [4]	1,386,419	2,185,346
SPECIAL AMMUNITION.								
4 in. (Stokes)[6]	—	—	—	—	10,000	26,800	18,160	800
Livens drums	—	—	—	—	—	—	—	—

The figures denote filled production.
[2] Excluding 95,100 deliveries by Roburite and Ammonal Co. from 26 May, 1915 to 27 November, 1915.
[3] Including 95,100 deliveries from Roburite and Ammonal from 26 May, 1915, to 27 November, 1915.

(CHAPTER III.)

Mortars and Special Weapons.[1]

1916.		1917.				1918.			
3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.
885	432	431	573	748	1,247	1,931	531	1,260	1,263
151	22	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
6	1	1	—	—	—	—	—	—	—
118	132	190	302	187	91	—	19	—	—
—	—	—	586	599	744	64	448	79	18
74	50	3	—	—	—	—	—	—	—
—	—	—	34	63	27	68	11	132	1
—	—	—	30	59	27	10	19	12	5
—	—	—	—	—	9	2	—	—	—
1,234	637	625	1,525	1,656	2,145	2,075	1,028	1,483	1,287
58	22	19	150	51	23	25	113	305	44
—	—	19,865	3,340	17,793	23,537	14,070	16,320	29,065	21,090

[3] An additional 88 noted in one return only have not been traced further. The number was probably due to a clerical error.
[4] Of these, 30 were despatched to France in September, 1915.

(CHAPTER III.)

Mortar, and Special, Ammunition.[1]

1916.		1917.				1918.			
3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.
63,719	—	—	—	—	—	—	—	—	—
28,332	—	—	—	—	—	—	—	—	—
1,138,558	1,007,651	1,028,240	648,758	1,337,320	865,143	538,404	1,184,130	982,267	591,693
4,428	—	—	—	—	—	—	—	—	—
1,676	88	—	—	—	—	—	—	—	—
205,371	310,157	178,195	243,918	276,887	47,033	—	—	—	—
—	—	—	13,704	86,843	138,924	187,979	304,168	473,953	168,705
60,906	72,338	82,025	22,533	64,913	17,531	6,022	320	2,304	—
1,502,990	1,390,234	1,288,460	928,913	1,765,963	1,068,631	732,405	1,488,618	1,458,524	760,398
524	9,082	83,984	237,334	146,128	50,209	9,505	18,014	4,757	5,493
—	—	—	over 25,000 [5]	33,015	48,215	18,892	49,655	56,013	7,888

[4] Includes 3 in., 1 January, 1916.
[5] The filling figures for projector drums in 1917 are incomplete. The total number filled during the whole year was 144,425 (HIST. REC./H/1650/10, p. 104). [6] Exclusive of smoke bombs.

APPENDIX XII.

(CHAPTER IV.)

List of the Chief Service Grenades.

1—R.L. Hand, Percussion.
2—Mexican, Hand, Percussion.
3—Hale, Rifle, Percussion (Rodded).
4—Naval, Rifle.
5—Mills, Hand, Time.
6—R.L. Hand (Light), Time (Friction).
7—R.L. Hand (Heavy), Time (Friction).
8—Double Cylinder, Hand (Light), Time.
9—Double Cylinder, Hand (Heavy), Time.
10—Naval, Rifle.
11—Naval, Long, Rifle.
12—Hairbrush, Hand, Time.
13—Pitcher (Light), Hand, Time.
14—Pitcher (Heavy), Hand, Time.
15—Ball, Hand, Time.
16—Oval, Hand, Time.
17—R.L. Opera-hat, Rifle.
18—R.L. Hand, Percussion.
19—T.W.D. Hand, Percussion.
20—Vaneless, Rifle (Rodded), Percussion.
21—" R," West Spring Gun.
22—Newton, Pippin, Rifle (Rodded), Percussion.
23—Mark I Mills, Rifle (Rodded), Time.
Mark II Mills, Hand or Rifle (Rodded).
Mark III (Remodelled), Time.
24—Rifle, Rodded, Percussion.
25—Sangster, Rifle, Percussion.
26—Red Phosphorus, " C.," Hand.
27—White Phosphorus, Hand or Rifle (Rodded), Time.
28—" M.S.K." Spherical.
29—P.O.P. Lachrymatory.
30—Humphrey, Hand or Rifle, Percussion.
31—Signal, Day, Rifle (Rodded), Time.

32—Signal, Night, Rifle (Rodded), Time.
33—Hillite (Capsicine), Hand, Time, "D" and "E," Spherical.
34—Egg, Hand, Time.
35—Rifle (Rodded), Percussion.
36—Mills, Hand or Rifle (Rodless), Time.
37—Phosphorus, Hand or Rifle (Rodless), Time.
38—Signal, Night, Rifle (Rodded), Time.
39—Steuart, Rifle (Rodded), Time.
40—Experimental.
41—Chemical.
42—Signal, Day, Rifle (Rodless), Time.
43—Signal, Night, Rifle (Rodless), Time.
44—Anti-Tank, Rifle (Rodded), Percussion.
45—Signal, Night, Rifle (Rodless), Time.
46—Anti-Tank, Rifle (Rodded), Percussion.
47—Experimental.
48—R.A.F., Rifle, Time.

APPENDIX XIII.

The Output

	1914.		1915.				1916.	
	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.
Hand—								
No. 1 Percussion	Inclu	ded in	the Gran	d Total.	113,324[2]	102,515[2]	69,617	89,252
No. 2 Mexican..	Up to	2nd Q	r., 1916,	small qu	antities wer	e produced	by Cotton	Powder Co.
Pitcher	—	—	—	—	121,624	10,008	—	—
Ball	—	—	—	—	1,670,332	4,237,188	212,480	138,133
Oval	—	—	—	—	11,000	603,964	478,668	1,584,480
No. 5	—	—	—	—	292,396	4,536,090	7,040,340	2,884,933
No. 19	—	—	—	—	—	—	—	494,685
No. 34	—	—	—	—	—	—	—	—
Total	Inclu	ded in	the Gran	d Total.	2,208,676[3]	9,489,765[3]	7,801,105[3]	5,191,483[3]
Rifle—								
Nos. 3, 20, 24 and 35 ..	Small Cot	quant ton Po	ity prod wder Co.	uced by (No. 3)	29,600	191,070	328,260	1,048,832
No. 22	—	—	—	—	—	—	—	171,035
No. 39	—	—	—	—	—	—	—	—
No. 44 A.T.	—	—	—	—	—	—	—	—
Total	Small	quanti	ties of No	. 3 only.	29,600	191,070	328,260	1,219,867
Hand or Rifle—								
No. 23	—	—	—	—	—	—	—	—
No. 36	—	—	—	—	—	—	—	—
Total	—	—	—	—	—	—	—	—
Smoke—								
No. 26 "P"	—	—	—	—	116,800	180,456	171,960	133,146
No. 27	—	—	—	—	—	—	—	—
No. 37	—	—	—	—	—	—	—	—
Total	—	—	—	—	116,800	180,456	171,960	133,146
Chemical—								
No. 28 "M.S.K."	—	—	—	—	—	—	—	—
No. 33 "Hillite"	—	—	—	—	—	—	—	—
No. 41	—	—	—	—	—	—	—	—
Total	—	—	—	—	—	—	—	—
GRAND TOTAL ..	2,164[4]		24,009[4]	41,306[4]	2,355,076[5]	9,861,291[5]	8,301,325[5]	6,544,496[5]

[1] The figures denote filled deliveries.
[2] Inclusive of other R.L. types.
[3] Without Mexican No. 2.

(CHAPTER IV.)

# of Grenades.[1]

1916.		1917.				1918.			
3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.	1st Qr.	2nd Qr.	3rd Qr.	4th Qr.
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—
188,109	—	—	—	—	—	—	—	—	—
1,153,463	—	—	—	—	—	—	—	—	—
5,714,017	8,596,871	3,975,328	124,336	4,056	—	—	—	—	—
311,465	—	—	—	—	—	—	—	—	—
—	—	—	—	—	50,835	575,951	497,040	395,201	254,495
7,367,054	8,596,871	3,975,328	124,336	4,056	50,835	575,951	497,040	395,201	254,495
629,383	1,136,356	505,953	1,153,224	1,127,889	1,880,645	2,104,165	1,978,457	402,475	11,470
[illegible]	596	92,980	334,832	147,281	—	33,058	—	—	—
[illegible]	—	—	—	—	—	—	500	654,885	304,466
[illegible]	—	—	—	—	—	—	1,470	85,453	10,858
[illegible]	1,136,952	598,933	1,488,056	1,275,170	1,880,645	2,137,223	1,980,427	1,142,813	326,794
[illegible]	1,198,549	2,393,601	6,171,760	6,157,745	3,158,924	2,152,148	4,067,366	2,547,339	1,259,410
—	—	—	—	63,307	1,151,566	132,188	1,276,132	1,416,918	1,208,932
804,993	1,198,549	2,393,601	6,171,760	6,221,052	4,310,490	2,284,336	5,345,498	3,964,257	2,468,342
105,477	120,079	144,188	131,017	77,770	43,663	109,408	159,413	78,185	—
—	—	6,904	56,299	53,004	123,554	285,100	370,000	484,033	100,000
—	—	—	—	—	—	—	24,100	77,126	123,852
105,477	120,079	151,092	187,316	130,774	167,217	394,508	553,513	639,344	223,852
—	—	—	25,533	37,154	33,405	118,087	199,095	95,022	54,850
—	—	—	—	—	—	6,400	10,720	9,719	11,771
—	—	—	—	—	—	—	—	11,200	23,208
—	—	—	25,533	37,154	33,405	124,487	209,815	115,941	89,829
8,969,694	11,052,451	7,118,954	7,997,001	7,668,206	6,442,592	5,516,505	8,586,293	6,257,556	3,363,312

[4] Excluding Cotton Powder Co.'s output of Hale rifle and Mexican grenades.
[5] Including the Hale Rifle grenade, but not the Mexican.

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VOLUME XI

THE SUPPLY OF MUNITIONS

PART II

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CHAPTER I.

THE DEVELOPMENT OF CHEMICAL WARFARE.[1]

On 22 April, 1915, the first German gas offensive on the Western front surprised and broke the French forces at Ypres. Throughout the War the enemy maintained an unbroken and unenviable priority in adopting and developing the offensive toxic substances which gradually increased in the severity of their effects. During the first week in May, 1915, British troops were first subjected to attacks with clouds of chlorine, which the Germans were then using alone or in admixture with bromine. By this time, the public appeal, which had been issued by the Government immediately after the gas attack upon the French, had provided every British soldier on the Western front with some form of improvised protection, generally a mouth-pad soaked in some neutralising solution. The issue of gas helmets began on 10 May, 1915. Thenceforward, so far as concerned matters of defence, the initiative rested with the Allies, and the enemy never afterwards used in any quantity any gas against which British authorities were unwarned or British troops entirely unprepared.

I. The Beginnings of Chemical Warfare (December, 1914—April, 1916).

Under Appendix III of the Hague Convention, the contracting Powers agreed on 29 July, 1899, to " abstain from the use of projectiles, the sole object of which is the diffusion of asphyxiating or deleterious gases." The indefinite wording of this clause left it open to the contracting parties to interpret its terms somewhat widely and to consider permissible (*a*) the use of preparations giving rise to disagreeable fumes without causing permanent harm or (*b*) the introduction of gas into high explosive shell. It was ruled by the Foreign Office before the outbreak of war that either of these interpretations was admissible, and during 1913–14, in view of indications that the subject was being considered in other countries, the War Office initiated trials of certain lachrymators (chloroacetone and benzyl chloride) in small high explosive shell. The Superintendent of Research reported unfavourably on the offensive effects of these substances on 29 August, 1914, and the adoption of such chemical shell was negatived by both Services a month later. Various proposals for the use of more noxious substances were rejected as contrary to the terms of the Convention. In particular, the Army Council stated on 16 October, 1914, that suggestions, similar to one recently put forward for the use of prussic acid bombs from aeroplanes, were barred by these terms. Investigations, however, were continued as to the practicability of using " stink-bombs " to render a trench untenable by temporarily incapacitating its occupants. These were carried out by the Chemical Sub-Committee of the Royal Society War Committee, which was established to consider chemistry in relation to the War on 12 November, 1914.

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[1] Based, where no other reference is given, on HIST. REC./H./1650/9.

(*a*) Irritants in Stink Bombs.

Official efforts to provide irritant fillings for hand-grenades or mechanically propelled bombs began early in December, 1914. Colonel (afterwards General Sir Louis) Jackson, of the Department of Fortifications and Works, consulted the Chemical Sub-Committee as to a request for " stink-pots " which he received from the Engineer-in-Chief about 3 December. In January, 1915, after some 50 different substances had been investigated, the choice of the War Office representatives fell upon a powerful lachrymator, ethyl iodoacetate, which was styled " S.K." after South Kensington where the experiments had been conducted.[1] This liquid was subjected to field trials in glass bottles inserted into tin canisters and fired by detonators. It was adopted because its manufacture did not encroach upon materials needed for other military purposes and because it did not react upon shell metal. Early in March, 1915, it was suggested to General Headquarters, France, that 1,000 S.K. grenades should be filled and stored in case the enemy should adopt similar methods ; but it seems that no action was taken to effect supply until the German offensive of 22 April, after which schemes were immediately set on foot for making S.K. and filling it into grenades as a preliminary form of retaliation. The preparation of twelve gallons of the liquid was completed by 21 May, 1915, and arrangements were made to push forward manufacture pending the measures for obtaining more noxious substances. By mid-August, 18,000 S.K. grenades had been prepared, and by January, 1916, 6,000 gallons of the liquid had been made.

(*b*) The Adoption of Lethal Cylinder Gas.

In their first offensives during April and May, 1915, the Germans chiefly used clouds of chlorine by itself or in admixture with bromine, and discharged from cylinders, and to a lesser extent lachrymatory substances in artillery shell.

British measures for retaliation began on 3 May, 1915, when Lord Kitchener definitely entrusted Colonel Jackson with the preparation of a reply. The production of bromine outside the German Empire was comparatively small and extremely costly. The manufacture of chlorine was comparatively cheap and a certain capacity already existed for its production in England. Its effectiveness as a cylinder gas had been proved by the German offensives. The first efforts of Colonel Jackson's section were accordingly applied to providing liquid chlorine in cylinders, which were very similar to those already in commercial use for transport purposes. In the meantime, G.H.Q., France, made frequent applications for the supply of some substance with which to retaliate effectively. On 23 May, 1915, Sir John French asked for prompt supply of asphyxiating gases in addition to the chemical grenades recently issued. He was then informed that cylinders of chlorine were being prepared and that the experiments in progress with other chemicals would take some time. On 16 June, he set out his general conclusions as to the gas offensive, *viz.*, that the

[1] For the code names used for the various chemicals see Appendix I.

first attack should be of the nature of a surprise, that for the time it should be restricted to a front of 5,000 yards, that the discharge should last thirty minutes, and that cylinder gas should be supplemented as soon as possible by more toxic substances in aerial bombs, gun shell, and trench mortar bombs.

Large scale trials with liquid chlorine in cylinders took place at Runcorn on 4 June, 1915. The first consignment was despatched to France on 10 July, and about 180 tons had been sent to France by 25 September, when special companies of the Royal Engineers made the first British cloud gas attack at the battle of Loos.[1] For this purpose the chlorine was issued in liquid form and unmixed with other substances and was known as "Red Star." It was subsequently used in admixture with other chemicals and formed the basis of almost every toxic substance produced throughout the war.

On 19 June, 1915, a conference on the defensive and offensive sides of chemical warfare was held at Boulogne between the Parliamentary Military Secretary to the Ministry of Munitions (Major-General Ivor Philipps), Colonel Foulkes, R.E., who was taking up the command of the special companies in course of formation, and Colonel Cummins, R.A.M.C. The size and number of cylinders for cloud attacks was fixed and it was ruled that the danger of shell fire made it impracticable to replace these by pumping from a central factory under pressure in pipes.

At this conference, carbonyl chloride (phosgene) was mentioned as a suitable cloud gas. It produces effects similar to those of chlorine but is more dangerous since it does not give rise to a spasm of the glottis which in the case of chlorine limits the breathing. Investigations as to this substance, which was known as "Lancastrite," "Collongite" or "C.G.," were undertaken in Great Britain towards the end of June, 1915, and in France at about the same time. No British process or plant existed for its manufacture; but a method of preparation from pure carbon monoxide and pure chlorine in the presence of a catalyst had previously been worked by a French firm. This firm began manufacture on a small scale at Calais by August, 1915, charging the product into bombs in admixture with stannic chloride (K.J.), which added weight and produced smoke for ranging purposes. The French makers refused to reveal their trade secrets, but by November, 1915, arrangements were made whereby the French Government exchanged for British chlorine a certain quantity of phosgene, which was charged at Calais into cylinders in admixture with 50 per cent. of liquid chlorine, the mixture being styled "White Star." It was accepted for service use in January, 1916, and was the cloud gas mainly used during the Battle of the Somme. This mixture had already been employed by the Germans about Christmas, 1915; but previous study of its properties had enabled the anti-gas authorities to devise protective measures, thus preventing many casualties, which would otherwise have been suffered in this attack. The use of chlorine by itself was thenceforward abandoned, since an efficient means of protection against it had been speedily devised by both sides.

[1] X/C.W./2078.

Certain other admixtures which were investigated as cylinder gas during the latter half of 1915 were ultimately rejected, mainly on tactical grounds. A noteworthy instance was that of "Blue Star," which consisted of sulphur chloride and liquid chlorine, and was abandoned after tests in France early in 1916.

(c) Offensive Substances in Emergency Grenades.

Pending the development of cylinder gas, various chemical substances were issued to France in grenades, as a means of immediate retaliation. The hasty manufacture of containers for the first of the grenades so issued in May, 1915, led to leakage, and the mixtures used proved unstable. These were (*a*) sulphur dioxide, an irritant, and (*b*) carbon bisulphide, an incendiary and asphyxiating material long used in destroying animal pests. Both were issued in admixture with a sternutator, capsicine, to increase their efficiency. It was, however, decided at the Boulogne conference on 19 June, 1915, that they had no military value. General Jackson's project for supplying large quantities of irritating and asphyxiating grenades for daily "hates" in the trenches received little support. At the same time, it was laid down that the substances supplied in hand-grenades should not be highly lethal, since they were intended for close-range work in the attack of trenches to be shortly occupied by friendly troops. With the exception of S.K., the materials issued to France in emergency grenades during the latter half of 1915 could, therefore, be classed only as "annoyers." They were "Hillite," a mixture of capsicine and magnesium carbonate, "Westonite" consisting of sulphur chloride and bromine, and "Fumite" or white phosphorus. Their effects necessarily fell below the anticipations of troops who were looking for widespread and intense results from the use of chemicals with which they were entirely unfamiliar. In January, 1916, the General Staff decided definitely that "annoyers" had no longer any military value. They were accordingly withdrawn from service use, and the S.K. lachrymatory grenade was also abandoned.

Phosphorus was, however, retained as a smoke producer, both to provide a screen, for which purpose it was introduced in the 4-in. Stokes and 2-in. trench mortar bombs during the Battle of Loos, and for signalling purposes in grenades.[1] Its use had first been approved on 23 June, 1915, and it continued to be the chief filling in 4-in. Stokes mortar bombs until the latter half of 1917. The development of mixtures for smoke and incendiary purposes is described in a separate chapter.[2]

(d) The Introduction of Lachrymatory Shell.

Broadly speaking, compounds available for chemical warfare may be classed as (*a*) cloud-producing substances which can be discharged by compressed air or gas from cylinders, and (*b*) substances which must be dissipated by means of a bursting charge in shells or grenades. The former class are mostly liquefiable gases or liquids of

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[1] See Vol. XI., Part I, pp. 84, 93 [2] See below, Chapter VII.

low boiling-point, which issue from the cylinder as a fine spray, evaporating immediately and causing great reduction of temperature, which aids in keeping the gas low. The latter are mostly solids or liquids which boil above atmospheric temperature. Certain of them can be mixed with liquefiable gases and so used as cylinder gas.

The first British chemical shells were designed to hold liquid chlorine, one type being modified from the 18-pdr., and one from the 4·5-in. howitzer, H.E. shell; but further experiment with chlorine was abandoned early in August 1915,[1] since it was too widely dispersed by the large bursting charge required in the shell. The "chlorine" shell was, however, used with an S.K. filling pending the development of a suitable cast-iron shell in which there should be no attempt to combine high explosive with lachrymatory effect.

On 16 June, 1915, Sir John French asked that cylinder gas should be supplemented as soon as possible with more poisonous gases in aerial bombs and shells. At the Boulogne conference, on 19 June, it was laid down that gas used in shell might be as deadly as gas in cylinders. It was also stated that the German dibromoxylene had proved to be a very effective lachrymator. The first trials of S.K. in artillery shell took place on 23 July, and steps were immediately taken to fill 2,000 4·5-in. and 500 18-pdr. "chlorine" shell with S.K. These were filled by the beginning of October, 1915. The available supply of converted shell was soon exhausted and considerable delays occurred in the production of experimental shell of the new designs under development. The design for cast-iron 4·5-in. shell was approved towards the end of October, 1915, when as a direct result of the Battle of Loos[2] 10,000 were ordered for trial with a lachrymatory filling. They were completed and issued charged with S.K. by the end of April, 1916.[3] In the meantime, on 5 February, 1916, the War Office had formulated definite requirements for a continuous supply of lachrymatory shell.[4] The adoption of lethal shell came somewhat later.

II. Developments in the Use of Chemicals (April, 1916—November, 1918).

(a) THE INTRODUCTION OF LETHAL MIXTURES IN ARTILLERY SHELL (1916).

The German assaults on Verdun began on 10 April, 1916, and as a direct result of the prolonged struggle for this fortress, during which the enemy made free use of lethal substances in artillery shell, the British Government definitely authorised similar methods and highly lethal shells were introduced into service use.

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[1] D.M.R.S. 91.
[2] D.M.R.S. 296.
[3] HIST. REC. /H./1650 10, pp. 98.
[4] D.M.R.S. 296.

From the beginning of 1916, the Commander-in-Chief, France, had asked continually to be supplied with lethal shell for the artillery.[1] The first definite action towards providing these was taken on 10 March, 1916, when the Government authorised the provision of a factory for charging shells with C.G., arrangements for charging shells with one of two prussic acid mixtures (J.L. or V.N.), and the accumulation of a reserve of the prussic acid shells in case their use should be required.[2] Intelligence reports had already given ground for a belief that the enemy was about to use prussic acid mixtures. On 16 May, 1916, the Commander-in-Chief expressed a definite preference for lethal, over lachrymatory, shells. As yet, however, the effect of detonation on C.G. or J.L. was uncertain. On 17 July, an urgent message requesting permission to use the J.L. shells was received from G.H.Q., France, and the necessary authority was given about 28 July.[3]

Investigations as to prussic acid mixtures had originated from the appointment on 3 May, 1915, of an Admiralty Committee to consider chemical gases. As a result of experiments carried out at the Kingsnorth Airship Station, this Committee had already recommended the use of J.L., a mixture of prussic acid, chloroform and triacetyl cellulose, which was named "Jellite" or J.L. on account of its jelly-like consistency. V.N., or "Vincennite," a French mixture, consisted of prussic acid, chloroform, stannic chloride and arsenious chloride. The comparative results obtained with these two mixtures were investigated during the summer of 1916. Towards the end of October, 1916, V.N showed definite superiority and was accordingly adopted in place of J.L. Pending the conversion of the J.L. plant for V.N. manufacture, J.B.R., a mixture of jellite and arsenious chloride (B.R.), was used in place of J.L. until V.N. became available in March, 1917.[4] The purely lethal mixtures issued in 1916 were thus J.L., J.B.R., and C.B.R. This last was an admixture of C.G. with arsenious chloride (B.R.), which had been recommended for service on 27 May, 1916. A design for C.B.R. shell was evolved by 28 August, 1916, and charging thereupon began.

Issue of the S.K. lachrymatory shell was continued and the use began of a new substance partly lachrymatory and partly lethal in its effects which was approved as a shell filling on 26 April, 1916. This was chloropicrin or P.S., so named from Port Sunlight where experimental production was effected. By the end of the year 1916, 160,000 shell had been filled with lethal or partly lethal mixtures and the general use of lethal substances in artillery shell had become an accomplished fact.

(*b*) CHANGES IN THE NATURE OF CLOUD GAS.

The use of cylinder gas reached its climax in the summer of 1916 during the Battle of the Somme, when 110 discharges took place, chiefly of the White Star mixture (chlorine and phosgene).[5] A new

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1 D.M.R.S. 296.
2 *Ibid.*
3 C.R. 4431.
4 D.M.R.S. 296*A*.
5 X./C.W./2078.

substance first issued in July, 1916, was "Green Star," a mixture of sulphuretted hydrogen and P.S. The adoption of sulphuretted hydrogen for lethal purposes had been under consideration since May, 1915, but it was not until the summer of 1916 that it was successfully adapted for use as a cloud gas by admixure with P.S., which weighs more heavily and kept it low. The cylinders of Green Star Mixture were allowed to accumulate in France and at home in order to obtain the tactical advantages of a surprise attack with large quantities. In the meantime, about 75 per cent. of the cylinders had corroded and the disadvantages of the mixture, particularly its inflammability impressed themselves upon the minds of the military authorities. Accordingly, it never actually passed into use, being definitely abandoned as a service store in July, 1917.

During the year 1917, cylinder gas was in less demand than before partly because of the development in the use of chemical shell, and mainly by reason of the large amount of labour required for bringing up and emplacing the cylinders. This disadvantage was overcome by the introduction of the Livens projector which was originally extemporised as a flame projector, afterwards used for discharging gas at Thiepval in September, 1916, and subsequently developed as a service store of great offensive value.[1] C.G. was approved as the filling for projector drums in March, 1917, and was the substance mainly used in them throughout the war, although, as the result of a successful demonstration with P.S., comparatively small numbers were filled with N.C., a mixture of P.S. and stannic chloride.

(c) DEVELOPMENTS IN THE USE OF LACHRYMATORS.

In the autumn of 1916, renewed inquiry was made as to fillings for hand-grenades suitable for clearing dug-outs during an attack. It was essential that the substance should penetrate German but not British masks, and that it should be readily cleared for the entry of friendly troops. The first grenades supplied for this purpose were filled with the lachrymatory mixture S.K., which did not fulfil the above requirements; by June, 1917, a less persistent substance, stannic chloride (K.J.), was accepted as it fulfilled all the conditions. Issue of grenades filled with K.J. had begun by September, 1917.

In the spring of 1916, lachrymatory mixtures had also been adopted for another short-range weapon, the 4-in. Stokes mortar. Bombs for this mortar had previously been utilised for smoke production only, for which purpose they had been issued filled with phosphorus in September, 1915.[2] The first lachrymator used in this bomb was S.K., sanctioned in April, 1916. Towards the end of that year the lethal and lachrymatory mixture P.S. was also issued in these bombs and in 1917 it became the main filling for them.

The purely lachrymatory substance, S.K., had at first been filled into shell in admixture with 25 per cent. of alcohol, partly in order to economise iodine and partly to standardise the weight of chemical

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[1] See Vol. XI, Part I, p. 99. [2] See Vol. XI, Part I, p. 93.

shells with that of high explosive ammunition. In March, 1917, it was definitely proved that the efficiency of shells filled with pure, alcohol-free ethyl iodoacetate was greatly superior to that of the S.K. shells then in service. Accordingly the use of the alcohol-free mixture, called K.S.K., was approved as an alternative; but the shortage of acetic acid during 1917 and 1918 greatly restricted its use and even necessitated the issue of S.K. with a considerably increased proportion of alcohol. Although its effects were purely lachrymatory, S.K. remained in demand for neutralising purposes by reason of its superior persistency until 1918, when it was about to be superseded by a still more persistent toxic compound, H.S.

(*d*) New Types of Lethal Chemicals.

While S.K. remained the standard lachrymator throughout the war, a greater variety characterised the more lethal substances first issued. This was partly due to the experimental nature of the use of chemicals as offensive agents, partly to conditions of supply, and partly to tactical considerations. In May, 1916, the General Staff began formulating their requirements in general terms showing the results desired rather than the particular substance to be supplied. It was then laid down that trench mortar bombs should be filled (*a*) with smoke mixtures and (*b*) with lachrymators only, while the substances supplied in chemical shell were to be lethal, although lachrymatory shell could be substituted, if the supply of lethal shells fell short. A year later this policy was reversed. In May, 1917, it was ruled that artillery projectiles should chiefly have a neutralising effect, and a small proportion only were to be lethal. Trench mortar bombs, on the other hand, were chiefly to have a killing effect, only a few being required for neutralisation. All projector drums were to have a killing effect.

Experience and research had speedily revealed defects in the lethal mixtures adopted, in 1916. Thus P.S. and J.L. decomposed upon detonation of the shells as first designed. Issue of P.S. shells was accordingly suspended from August, 1916, until the following February, when a more satisfactory burster was evolved. Shortly afterwards, a mixture of P.S. and K.J., styled N.C., was found to be superior both in toxic and penetrative effect. It was accordingly adopted in trench mortar bombs and superseded P.S. in artillery shell. From April, 1917, onwards, J.B.R. was gradually superseded by V.N., but in the following autumn V.N. fell into disrepute and was finally abandoned during the winter of 1917–18. P.G., a mixture of P.S. and C.G., was sanctioned as an alternative to N.C., in order to relieve supply, in September, 1917.

The military policy laid down in May, 1917, was thus met by issuing S.K. and N.C. or P.G. as lachrymatory and persistent, and V.N. and C.B.R. as non-persistent and lethal, fillings for artillery shells. Designs for shells capable of taking C.G. by itself were evolved during the year and eventually this filling superseded both V.N. and C.B.R. It was the only lethal substance allocated to projector drums; but greater variety was introduced in the 4-in. Stokes trench mortar bombs. These

were charged with C.G. and A.K. (a mixture of prussic acid and S.K.) as well as with S.K. and P.S.; but substances containing arsenious chloride (B.R.) were excluded, since this substance attacked the brass gaine of the bomb. The 4-in. bombs were slow in coming into supply. Hence, 2-in. trench mortar bombs filled with C.G. were issued temporarily during the early months of 1917.

Until 1918 the offensive substances used by Great Britain, with the exception of the standard lachrymator, S.K., were all based on the well-known toxic agents, chlorine, phosgene, chloropicrin, and prussic acid, used in various combinations with each other or with other non-toxic materials. These substances had chiefly affected the lungs and heart. In July, 1917, the enemy began to use a form of "mustard gas," which was not only highly toxic, but also produced serious burns and was extremely persistent in its effect and insidious in its nature. The problem of defence was thus widened since it was no longer restricted to guarding the eyes, nostrils, and mouth during comparatively short intervals, but involved the protection of the whole person for long periods of time. Measures were taken to reproduce this new substance, which was identified as dichlorethyl-sulphide, and styled "H.S."; but owing to circumstances which are described below the actual production of H.S. in bulk and its filling into shells did not begin until August, 1918, *i.e.*, just a year after the formulation of a demand by G.H.Q.[1]

At the same time that the Germans began to use mustard gas upon the Western front, they also adopted other new compounds in the nature of aromatic chlorarsines. A method of using arsenic compounds which had very violent physiological effects was evolved in imitation. Projects for producing triphenylarsenic dichloride (T.D.) were set on foot in January, 1918, and were subsequently abandoned in favour of other compounds, known as D.A. and D.M. These were scarcely beyond the initial stages of manufacture when hostilities ceased in November, 1918.

The system of specifying desired effects rather than particular substances which was begun in May, 1916, was definitely followed in the ruling of the following May as to the use of neutralising and killing substances, and in requests put forward in August and September, 1917, for the issue of persistent substances (H.S. and S.K.) as shell fillings, and non-persistent substances for short-range weapons.[2] A definite tactical policy thus replaced the earlier empirical methods. Research gradually came under the control of strategic requirement and the types of substance issued depended upon definite military criteria. The outstanding feature in the policy adopted by British authorities was the limitation in the number of types of filling used and concentration upon certain classes with particularly highly developed physiological properties for definite tactical purposes. Thus the 1919 programme as finally formulated in August, 1918, provided for the use of only two mixtures (C.G. and H.S.), in addition to comparatively small requirements of arsenic compounds.[3] This method contrasted

[1] D.M.R.S. 296 W. [2] D.M.R.S. 296 A.1. [3] M.C. 1049.

remarkably with the French policy of adopting more numerous substances with partially developed aggressive properties.[1] It was, however, on a line with the military policy of Great Britain, which demanded high-class equipment tested by experience for well-defined purposes. In practice, it was of necessity modified by circumstances of supply which are described in detail below.

III. Growth in the Demand for Chemical Supplies.[2]

Until tests had been made as to the practicability of producing the various substances which were approved for the service, and until decision had been taken to use the more lethal mixtures, no definite programme of the requirements was formulated. Thus, the amount of cylinder gas first issued was limited only by the manufacturing capacity available, and the demands for cloud gas generally were the subject of personal discussion between the officers concerned with its use and its supply. The first definite numerical requirement for chemical shells was a request for 10,000 lachrymatory shells which was received in October, 1915. These trial shells were issued in the following April, and in May, 1916, G.H.Q., France, again asked for definite numbers of chemical projectiles, *viz.*, 200,000 4-in. Stokes bombs to be filled with smoke and lachrymatory mixtures, and 40,000 artillery shells, lethal and lachrymatory. Issue of these was requested by the end of the following June; but this proved impracticable.

The requirements for chemical projectiles were first stated on a weekly basis in August, 1916. The number required advanced continuously from the 50,000 shells and bombs per week then laid down up to 336,000 shells, bombs and projectile drums per week, the number required in August, 1918, for the 1919 programme. The weight of chemicals desired weekly rose during the same period from 112 tons to 795 tons, exclusive of the White Star Mixture required for filling cylinders and of the more or less experimental requirements for arsenic compounds in smoke generators and for chemical fillings in aircraft bombs.[3] From August, 1916, until November, 1917, the requirement for cylinder gas was entirely suspended. Thereafter delivery was asked of a fixed number, eventually stated as 132,500, for issue by the end of March, 1918. This demand also was fixed on a weekly basis of 2,500 cylinders for the 1919 programme.

The general advance in the demand for chemicals as instruments of warfare reached its climax in the year 1918. In March, 1918, the Minister (Mr. Churchill) urged the military authorities to take advantage of the opportunities for gas attacks on a large scale on the Western front. Systematic meteorological investigations had shown that the number of days which were favourable to the use of cloud gas by the British forces was twice as many as those which gave the advantage to the enemy. At this date, it was intimated unofficially that the programme of gas warfare for 1919 would probably be double that

[1] Hist. Rec./H./1650/15. [2] Hist. Rec./H./1650/10. Parts IV and VI.
[3] See Appendix II.

for 1918. The main problems to be overcome were the provision of the necessary transport, *personnel* and guns, the allocation of sufficient tonnage, and the development of measures to secure the safety of the friendly civilian population behind the enemy's lines.[1] Early in April, the Minister gave instructions that extensions should be arranged to manufacture chemicals up to the extreme practicable limit for 1919, at the same time sanctioning schemes for doubling the output of the basic material, chlorine, to lay down plant for another 50 tons of C.G. weekly and for as much H.S. as possible.[2] The possibility of trebling the programme was also considered and steps were taken to develop and supply an overhead ropeway to facilitate the transport of cylinders up to the front.[3] The use of much larger natures of chemical shells, *viz.*, 8-in. and 9·2-in., was sanctioned early in the year. In June, a demand was formulated by the War Office, restricting the substances to be used in 1919 to H.S. and C.G. Until this date, the manufacturing programme to which the supply officers were working allowed for the production of 700 tons of these two fillings weekly in addition to comparatively small quantities of N.C. and of the arsenic compounds.[4] Schemes for increasing the output of H.S. alone to 1,000 tons weekly were thereupon considered.[5] In July, 1918, preparations began for producing arsenic compounds in bulk.[6] The final 1919 programme doubling the 1918 weekly demands was received from the War Office in August, 1918.[7] During the summer nearly one-third of the shells fired by the artillery were filled with chemical substances. The enormously increased programme for 1919 included projects for their use from tanks, aeroplanes and other natures of trench-mortar than the 4-in. Stokes.

These plans for an enormous increase in chemical production were practically brought to a standstill by the Armistice. Very considerable delays had attended the provision of chemical supplies throughout the war. These were due partly to the tardy formulation of requirements, partly to grave difficulties experienced in establishing a satisfactory administrative procedure, and largely to the serious practical difficulties inherent in the development of novel and highly technical industries in a minimum of time. The means used for solving these problems are the subject of the chapters which follow.

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[1] M.C. 1060.
[2] M.C. 1049.
[3] See Vol. XII, Part V.
[4] X. 236/10.
[5] M.C. 1049.
[6] C.R./Filling/307, 321.
[7] See Appendix II.

CHAPTER II.

ADMINISTRATION AND PROCEDURE.[1]

I. Introductory.

The use of chemicals was a new and highly technical form of warfare which developed very rapidly. Accordingly, success in equipping the army with offensive agents and defensive apparatus depended very greatly upon the speed and ease with which experience could be interchanged between the authorities concerned. Administrative procedure thus attained an importance far higher than that usually enjoyed by mere office routine.

The enemy led the way in using novel and dangerous substances. The authority responsible for defence identified the new gas, evolved a means of protection and provided the necessary protective apparatus. From the inception of chemical warfare until the close of hostilities, these three functions in regard to defence were closely combined and the results were generally successful. The problem of establishing an efficient administrative organisation for the offence was far more complex. Retaliation usually took the form of imitation ; hence close touch with the defence authority was essential. Certain officials were needed to evolve a method of making the desired substance in bulk, to develop suitable containers, and to authorise the use of the new weapon, taking into account efficiency, safety and the general conditions of use. These officers were the research and design authorities, design being used technically to denote approval for service rather than development of pattern. The fitness of the new offensive agent for its ultimate use depended upon an exact knowledge of shifting conditions in the field. Hence, a close liaison of the army with the research and design authorities was essential. When a process for manufacture had been evolved, the initial stages of production needed careful watching by technical experts, a reason for close co-operation between the research and the supply authority. The duties of the latter included provision for the safety and health of the factory workers and a knowledge of the physiological effects of the substances produced, which came primarily from the defence authority. Experience, acquired at great cost, showed the disastrous consequences of any weakness in this complete circle of interdependence. The results of handling or using toxic substances in ignorance of their properties are sufficiently obvious. The ill-effects of a divided responsibility could be illustrated by more than one untoward occurrence. On one occasion, for instance, they took the form of an issue of 40,000 chemical shell with wrong bursters, which were practically useless and were returned for re-filling at a time when the current output was less than a quarter of the requirement.[2]

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[1] Hist. Rec./H./1650/8, 9, 10.   [2] D.M.R S. 296A.

II. Unity of Control (May, 1915—December, 1915).

Until December, 1915, the duties of research, design and supply were all vested in General Jackson, whose section of the Department of Fortification and Works was known as F.W.3.A, or Engineer Munitions, and whose charter dated from the instructions received from Lord Kitchener on 3 May, 1915. The actual use of chemical agents, *e.g.*, in gas cylinders and special grenades, lay with the special companies of Royal Engineers formed during the months of May to August, 1915,[1] and placed under the command of Major (now General) C. H. Foulkes towards the end of June. A central laboratory was also established at G.H.Q. about the same time.

General Jackson's section was transferred to the Ministry of Munitions on 23 June, 1915, becoming the Trench Warfare Department. This department was responsible for the supply of service mortars and grenades and for research, design and supply duties in regard to novel weapons for trench warfare and all special stores, *i.e.*, chemical substances, gas cylinders and special projectiles, including chemical bombs and grenades. In general, the functions of the Ministry at its formation excluded responsibility for design; but this duty was expressly reserved to the Trench Warfare Department by the Army Council on the ground that it was impracticable to sever design from supply in the case of experimental stores. The general development of the Trench Warfare Department during this period has been described elsewhere.[2] The connection between chemical warfare and trench warfare was maintained for more than two years. One result of this arrangement was that the chemical warfare authority was more closely concerned with the provision of the chemical weapons used by the Special Brigade of Engineers than with other chemical projectiles, *viz.*, artillery shell. The authority for designing artillery shell was the Director of Artillery, advised by the Ordnance Board, and experimental work was carried out by the officers responsible for investigating other classes of gun ammunition. Similarly, the duty of supplying the empty shells was performed by the supply officers of the Ministry of Munitions responsible for producing other kinds of empty shell. The Trench Warfare Department produced the chemical substances and later became responsible for the charging of shells, which was generally carried out at the chemical works. During the period under consideration, however, the only chemical shells actually filled were the comparatively few 4·5-in. which were charged with S.K. at Walthamstow, a charging station directly controlled by the Trench Warfare Department.[3] During this period technical advice was obtained by General Jackson from a committee of experts, appointed as the Scientific Advisory Committee of the Trench Warfare Department in June, 1915.[4] This committee included several members of the Chemical Sub-Committee of the Royal Society War Committee, whose investigations it continued.[5]

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[1] HIST. REC./R./1650/27.
[2] Vol. XI, Part I, pp. 7-13.
[3] HIST. REC./H./1650/10, p. 59.
[4] Appendix III, No. 4.
[5] See above, p. 1.

In addition, a panel of experts representing the chemical industry, was appointed as the Commercial Advisory Committee of the Trench Warfare Department,[1] and met on 6 August, 1915, after which date its members were consulted individually. The chairman of both these committees was Mr. (afterwards Sir Alexander) Roger, who had been appointed financial adviser to the department upon its absorption into the Ministry of Munitions and became responsible for all questions relating to supply.

Contact with G.H.Q., France, was established by visits paid by Professor Crossley, who acted as secretary to the Chemical Sub-Committee of the Royal Society and afterwards as secretary to the Scientific, and Commercial, Advisory Committees. Colonel Foulkes, the commanding officer of the special companies, also attended certain meetings of the Scientific Advisory Committee and was in direct communication with General Jackson. The first laboratory scale experiments were carried out at various institutions and chiefly at the Imperial College of Science, South Kensington. No grounds were available for large scale trials; but experiments occasionally took place at the training school which was established on Clapham Common for general trench warfare purposes at the end of June, 1915. An experimental ground with workshop, laboratories and accommodation for trials on a very small scale was acquired at Wembley in the following August. The actual administration of supply questions relating to chemicals rested with the section (T.W.1) under Mr. Richmond, who was also in charge of the production of grenades, high explosive and chemical, and of cylinders. Two other supply sections dealt with nearly allied stores. The one (T.W.5) provided salvus apparatus, sprayers and flame projectors; the other (T.W.7), Stokes mortars, including the 4-in. mortar with its smoke ammunition.

III. The Separation of Research and Design from Supply (January, 1916—October, 1917).

The unity of control described above was abandoned in December, 1915, at the instance of Mr. Roger, who maintained that the interests of supply were suffering through subordination to those of research. Accordingly, the Trench Warfare Supply Department was constituted a separate unit within the Ministry, being responsible *inter alia* for the production of chemicals and containers for chemicals, with the exception of chemical shell. Experimentation was continued by General Jackson, whose staff was drawn chiefly from the military officials of the original Trench Warfare Department. Responsibility for design in the sense of approval of patterns was assumed by the newly constituted Director-General of Munitions Design, into whose department General Jackson's branch was gradually absorbed under the name of the Trench Warfare Research Department. This transfer, with the corresponding reorganisation of General Jackson's staff, was completed by June, 1916.

[1] Appendix III, No. 6.

(*a*) DEVELOPMENT OF THE DISTINCT ORGANISATION FOR SUPPLY.

In February, 1916, the Trench Warfare Supply Department was organised by Mr. Roger into ten sections, most of which were responsible for every stage in the production and issue of a complete store with all its component parts.[1] Three of these sections were concerned with chemical appliances. Section T.W.1 (under Lieutenant L. G. Shadbolt, R.N.V.R.) provided grenades, chemical and high explosive, and the non-lethal substances chiefly used in grenades; section T.W.2 (under Captain, afterwards Major H. Moreland) provided cylinders and the lethal substances then only used in cylinders; section T.W.7 provided Stokes mortars and their ammunition, including the 4-in. (special) Stokes bomb. The duties of T.W.1 included all arrangements for charging lachrymatory shell with S.K., inserting the bursting charges, and packing the filled shell with the necessary components. This work was all undertaken at the factory established at Walthamstow for filling S.K. grenades. Issue to the troops took place directly from the factory in accordance with the general practice of the Trench Warfare Supply Department. The empty shell and components, such as fuses, were provided by the departments of the Ministry respectively responsible for making and filling other types of shell.

With the abandonment of special grenades in January, 1916, and the introduction of lethal shell in the following summer, it became necessary to rearrange these duties. In November, 1916, the production of all chemical substances and the arrangements for charging and assembling every kind of container were concentrated in section T.W.2, which was known thenceforward as the Chemical Section. This section administered all contracts and was responsible for the preliminary negotiations, which were subsequently referred to the finance and contracts sections for completion. It supervised the erection of plant by contractors under special arrangements made with the Munitions Works Board, whose procedure was found unsuitable for the erection of chemical plants. By means of a staff of technical representatives stationed at works, it supervised process, advised contractors on technical points and kept record of technical difficulties and the progress of output. Inspection of chemical substances was carried out by the "Inspection Department Chemical," *i.e.*, that branch of the Inspection Department which was concerned generally with the analysis of materials while the inspection of the completed chemical projectiles was the work of a department concerned with the inspection of gun ammunition (D.I.G.A.(A)). The charging of projectiles with chemicals was usually effected at the works where the substance was produced. S.K. only was made at one factory and charged at another, Walthamstow. In June, 1916, with the introduction of lethal shells, the responsibility for assembling the charged shells was to be allocated either to the Ordnance Factory, Woolwich, or to the Controller of Gun Ammunition Filling. This process involved the dual risk of handling chemicals and explosives. For a time, lethal shells were assembled at Woolwich,

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[1] The gradual abandonment of this system is described elsewhere (Vol. XI, Part I, pp. 11–12).

lachrymatory shells at Walthamstow, and other chemical projectiles at the Trench Warfare National Filling Factories. Actual experience with leaky shells at Woolwich led to the concentration of the responsibility for assembling all types of chemical projectiles in the Trench Warfare Supply Department, which erected and administered a special national factory for assembling lethal shell at Greenford.[1]

(b) DEVELOPMENTS IN THE ADMINISTRATION OF RESEARCH AND DESIGN.

The separation of responsibility for design, in the administrative sense of approval, from the functions of experiment and research was regarded by General Jackson and his expert advisers as a retrograde step and likely to lead to indifference, to delay, and to an academic, rather than a practical, treatment of research. They maintained that the normal procedure whereby the administrative chief passed sentence on proposals submitted by his subordinates engaged upon research was too cumbersome a method to ensure the speedy development of a new type of offensive agent during actual hostilities. They cited in illustration the speedy production of cylinder gas during the preceding period of centralised control, and the comparatively slow development of lethal shell for which responsibility had been sub-divided. They submitted that the reorganisation had two distinct disadvantages. In the first place, it hampered free communication between the research authority and the army in the field, so that misunderstandings arose as to the principles and uses of the materials supplied while informal information led only to confusion and delay. In the second place, the adoption of a rigid procedure for drawings and specifications which was necessary to the maintenance of the authority vested in the design officer, made it impossible for supply action to proceed until investigations were fully completed. The new position was only accepted after six months' discussion as to the principles involved. Difficulty continued in ensuring close enough touch between the research and supply authorities and will be discussed below.

A large part of the work of the Scientific Advisory Committee had been executed by a general chemical sub-committee, the members of which continued to advise General Jackson as Controller of Trench Warfare Research, and were formally appointed as the Chemical Advisory Committee on 2 February, 1916. At the same time a panel of advisers on Trench Warfare Research was nominated, and the Chemical Advisory Committee took the place of individual members of the panel in regard to all questions concerning chemistry.[2] The severance of the supply authority from the research authority had already been intensified by the resignation of Mr. Roger from the chairmanship of the Scientific Advisory Committee in December, 1915. He was succeeded in this office by the Controller of Trench Warfare Research (General Jackson), who became chairman of the Chemical Advisory Committee when it was formed. It worked under his direct

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[1] HIST. REC./H./1600/9, p. 9; see below p. 26.
[2] Appendix III, Nos. 6, 7.

control, meeting at first daily and afterwards weekly, forwarding reports of its investigations to all the departments concerned, and carrying out its daily business through a small administrative sub-committee, which existed until February, 1917. The Chemical Advisory Committee was responsible for all research in connection with chemical fillings; but proposed designs for containers, *e.g.*, shells and bombs, were referred to the Ordnance Committee before being submitted to the Director-General of Munitions Design for approval.

The outstanding administrative development of this period was the establishment of an adequate organisation for carrying out experiments. The early experiments with S.K. had been conducted under extemporised conditions at the Imperial College of Science, where an experimental chamber for bursting shell at rest was erected by March, 1916. The facilities for open-air trials on a large scale were slow in development. Cylinder gas trials were at first held at any place where the necessary facilities were available. The lack of ground for large scale trials had hampered research throughout 1915. The Grenade and Trench Mortar School established on Clapham Common in June, 1915, was occasionally used for minor experiments. The experimental ground at Wembley, acquired by the Trench Warfare Department in August, 1915, was too limited in extent for any but small scale trials. A project to establish a larger experimental ground was set on foot in September, 1915, but did not materialise until the following January, when a site at Porton was acquired and prepared for cylinder gas trials. Experimental work began at the Porton Experimental Ground in April, 1916, and in the following July the first artillery trials were carried out there. Thenceforward the work of the station developed more rapidly. In November, 1916, an experimental battery was detailed for permanent duty. Laboratories were built and extended, but it was not until the autumn of 1918 that their investigations related to any but the direct results of the trials. Officers with actual experience in the field were added to the staff. Liaison with defensive research was established in April, 1917, when officers were appointed to study the medical aspects of poisoning at Porton. An anti-gas department was established at the station in May, 1917. During the last year of the war the researches undertaken included investigations of great value regarding general questions such as the relative toxicity and persistency of poison gases. The work carried out at Porton included the proving of all chemical, incendiary and smoke shells, and an adjacent range was established at South Porton for trench warfare purposes.[1]

(*c*) ATTEMPTS TO CO-ORDINATE SUPPLY WITH DESIGN.

The alienation between the authorities for supply and research was strengthened by personal differences and intensified by a geographical separation which took place in February, 1917, when the Trench Warfare Research Department removed to another building.

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[1] HIST. REC./H./1650/14.

On the one hand, no representative of supply questions sat upon the Chemical Advisory Committee, although in considering new substances its members endeavoured to take into account the practicability of large scale production and the availability of raw materials. On the other hand, the first attempts to manufacture lethal substances in the spring of 1916 were carried out by the supply authorities without any reference of the technical difficulties to the Advisory Committee.

Various methods of securing some measure of co-ordination were adopted between March, 1916, and October, 1917. In the spring of 1916, the dangerous nature of arsenious chloride production and technical difficulties experienced in starting up the manufacture of C.G. led to an arrangement whereby members of the Chemical Advisory Committee paid periodical visits to chemical factories, and to the interchange of technical reports. In June, 1916, a liaison officer (Professor, afterwards Sir John Cadman, later succeeded by Dr. Alexander Scott) was appointed to keep touch between the research and supply authorities, acting as resident technical adviser to the Trench Warfare Supply Department and also as a member of the Chemical Advisory Committee. The position of such a technical adviser was rendered extremely difficult by reason of its tendency to create dual control in the works of contractors. After various attempts to solve this problem by defining and re-defining the functions of the liaison officer, another method of co-ordination was tried by the establishment of a Chemical Supplies Committee within the Trench Warfare Supply Department in April, 1917. The Director-General of Trench Warfare Supply presided over this committee and its members included the officers concerned with the supply of chemical substances, certain members of the Chemical Advisory Committee, including the liaison officer and the officer in charge of A.9, that section of the Directorate of Artillery which had recently been established to deal with Chemical Warfare.[1] The Committee succeeded in procuring a valuable interchange of information, but its general utility was considerably restricted by its purely advisory character.

(*d*) RELATIONS WITH THE ARMY IN THE FIELD.

The problem of establishing satisfactory liaison between research and design officers on the one hand, and the army in the field on the other, without undermining the central authority of the War Office was a difficulty inherent in the existence of a separate Ministry concerned with supply and design.[2] In the case of chemical warfare an attempt to obviate it was made by concentrating in one officer, Colonel Crossley, the duties of liaison with the Western Front and the control of experimental work at Porton. With the development of the experimental ground, however, it became impracticable for Colonel Crossley to devote much time to liaison. He was also the medium for communication with the French authorities until a separate establishment for interchanging information on Allied production and research was constituted in

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[1] Appendix III, No. 9.
[2] See Vol. IX, Part II, Chap. VI.

May, 1917.[1] A certain knowledge of conditions in the field was obtained by adding to the Porton staff officers who had recently served on the Western Front. The Controller of Trench Warfare Research was also entitled to communicate semi-officially with Colonel Foulkes and other technical advisers at G.H.Q. Closer co-ordination with the War Office was obtained through the representation of A.9 on the Chemical Advisory Committee towards the end of 1916, and on the Chemical Supplies Committee in April, 1917. These measures failed to improve the situation. They were abandoned in November, 1917, the date of a reorganisation, which involved also the concentration under one authority of the responsibility for the investigation and design of offensive agents and investigation, design and supply of defensive apparatus.

IV. The Partial Union of Offence and Defence (November, 1917—November, 1918).

(a) THE ADMINISTRATION OF RESEARCH AND SUPPLY FOR DEFENCE (MAY, 1915—OCTOBER, 1917).[2]

The provision of defensive apparatus had been undertaken by the Army Medical Department directly after the first German gas attack. For some time there was no authorised establishment for dealing with anti-gas problems; but experimental work was centred in the Hygiene Laboratory at the Royal Army Medical College, Millbank. The staff engaged upon the investigation and inspection of defensive apparatus developed rapidly after the autumn of 1915, and the section with its headquarters at Millbank became known as the Anti-Gas Department. Orders were placed through the Contracts Branch of the War Office and supply questions were considered daily by the Anti-Gas Supply Committee, which was appointed in July, 1915, and included representatives of the Army Ordnance and Contracts Departments in addition to certain contractors.[3]

At Millbank experimental work was carried out under the supervision of Major Lelean until the autumn of 1915, when he was succeeded by Major Starling. At this time chemical research and respirator design were mostly in the hands of Lieut. (afterwards Lieut.-Col.) Harrison, C.M.G., and Lieut. (afterwards Major) Sadd. In 1916, Colonel Harrison succeeded Major Starling, while Captain (afterwards Lieut.-Col.) Raper was placed in charge of the chemical laboratories.

Investigation as to the physiological problems arising out of the war was also undertaken by a sectional committee of the Royal Society appointed in June, 1915.[4] Its members included representatives of the Naval Medical Service, of the Medical Research Committee (National Insurance Act), and of the Director of Army Medical Services, who nominated as his representative an officer of the Anti-Gas Department.

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1 HIST. REC./H./1650/15.
2 HIST. REC./H./1650/3 (2).
3 Appendix III, No. 5. For the work of the Committee, see below, p. 69.
4 Appendix III, No. 3.

Thus it served to link together the research work of the various services, forming a common meeting ground where upon occasion the naval and military representatives first learned of new devices adopted by the sister service.[1] The Physiology Committee published in September, 1915, the first report on the results of experiments with toxic compounds carried out in the laboratories of its individual members. In July, 1916, at the instance of the Committee, the Trench Warfare Supply Department appointed a special medical officer (Dr. F. Shufflebotham) to investigate cases of gas poisoning among the factory workers and to take general control of medical conditions in chemical factories. He also acted as an assessor at the meetings of the Physiology Committee. The pathological researches conducted at Porton Experimental Ground grew in importance during the year 1917, as it became necessary to provide information as to the casualty producing, as well as the killing, capacity of various lethal agents.[2]

The establishment of the Anti-Gas Department at Porton provided a direct means of communication between officers concerned with research for offence and defence. Informal information had previously been secured through Professors Baker and Thorpe, who had acted as members of advisory committees on both sides, while from June, 1916, the Anti-Gas and Chemical Advisory Committees periodically held joint meetings which were also attended by the Medical Adviser to the Supply Department.

Satisfactory interchange of opinion with the British Expeditionary Force in various theatres of war was obtained by means of visits from officers of the Director of Gas Services, France, to the Anti-Gas Department and return visits by officers of the Anti-Gas Department. Anti-gas apparatus was thus submitted for criticism in the various stages of its evolution. From the summer of 1917 onwards, Corps Chemical Advisers and Divisional Gas Officers on leave in England were given facilities for visiting the anti-gas laboratories and factories. A close and efficient method was thus established for co-ordinating experience gained in research as to defensive apparatus and in its supply and use.

(*b*) Reorganisation, November, 1917.

During the summer of 1917 there were remarkable and rapid developments in the enemy's use of chemical agents, notably the adoption of mustard gas. In order to meet the new conditions, the Minister considered that a new impulse and a stronger organisation were needed. In September, 1917, the Chemical Advisory Committee was strengthened by the appointment of a panel of twelve eminent chemists with a view to widening the basis of research.[3] In the following month a total reorganisation of the authorities concerned with anti-gas and chemical research was announced. The Anti-Gas Department with its corresponding contracts section was transferred from the War Office to the

[1] Hist. Rec./H./1650/13 (3).
[2] Hist. Rec./H./1650/14.
[3] Appendix III.

Ministry of Munitions in November, 1917, so as to obtain closer co-operation between offensive and defensive authorities. In that month a new Chemical Warfare Department was established in the Ministry under Major-General H. F. Thuillier as Controller. The department was to comprise a committee consisting of the executive members in charge of sections concerned with research as to offence, and research and manufacture on the defensive side, and of advisory members chosen from eminent chemists and physiologists. These last included many members of the advisory committees previously established. *Ex officio* members of the committee included the Commandant Overseas Artillery School, Chemical Adviser, Home Forces, and representatives of the Gas Services in France, with a view to securing intimate relations with the army in the field. Supply questions were represented upon the committee by the various officers concerned with the production of chemical substances and their containers. Experimental work was represented by officers from Porton including the physiological experts. The panel of experts appointed in September continued to exist as a body of associate members with certain alterations and additions. The Trench Warfare Research Branch of the Munitions Design Department ceased to exist as a whole and the sections concerned with chemical agents and apparatus were absorbed into the new department. The experimental establishments at Porton and Wembley were also brought under the authority of the Controller. His functions included the approval of offensive substances and of defensive apparatus. The duty of approval or "design" in the technical sense was thus removed from the Department of Munitions Design, which retained only the duty of passing sentence on the patterns of chemical projectiles, *e.g.*, shells and bombs. On the other hand, both that department and the newly formed Chemical Warfare Department were placed within the "Design" Group of the Munitions Council, reporting to the Minister through Council Member D.

The activities of the new department were divided into four sections. One was under the late Lieut.-Col. E. F. Harrison, C.M.G., who had been connected with anti-gas research since 1915, and had been in charge of the Anti-Gas Department since the autumn of 1916. It retained all the duties of the anti-gas organisation under the War Office. Extended facilities for experimental work were obtained by removing its headquarters from Millbank to the Physiological Institute and other laboratories at University College, London. The anti-gas research section was mainly concerned with the development of new types of apparatus and with experiments in charcoal and granule production; but it also undertook routine control of output by laboratory tests and tests on the man during which respirators were tried in an atmosphere of poison gas. A more direct control over questions of anti-gas supply was secured by the development of a distinct section of the department for this purpose, and this section ultimately superseded the Anti-Gas Supply Committee.

The second unit of the new Chemical Warfare Department consisted of the Chemical Warfare Committee reporting to the Controller through a Deputy Controller, not immediately appointed. Closely connected

with the work of the Committee were the scattered institutions engaged upon research and an information bureau which was established in order to bring together all recorded knowledge on chemical warfare from foreign, as well as British, sources. The third unit consisted of the sections engaged upon technical research on the utilisation of offensive substances and the design of suitable apparatus for which the drawing office was primarily employed. The fourth unit was concerned with general administrative questions. Its duties included the control of the experimental grounds at Porton and Wembley.

The Chemical Warfare Department expanded rapidly during the first year of its existence. Systematic investigations at headquarters were supplemented by the work of numerous research students throughout the country. Study of details in the design of individual containers and apparatus was assigned to a Chemical Designs Committee in January, 1918, the Chemical Warfare Committee remaining responsible for questions of general policy relating to the use of particular substances. About the same time a Chemical Warfare Medical Committee was established. It consisted of the physiology sub-committee of the Chemical Warfare Committee and certain other physiologists, and was a link with the Director-General of the Army Medical Services, to whom it reported on the scientific medical aspects of chemical warfare from the knowledge acquired by the Chemical Warfare Department.

The representation of military authorities upon the Chemical Warfare Committee did not succeed in bringing into accord the views of scientists at home and artillerists in the field as to the methods of use of different types of chemical shell. Upon the resignation of General Thuillier, in October, 1918, an attempt was made to gain a still closer co-ordination by the appointment of the Director of Gas Services, France (Brig.-Gen. C. H. Foulkes), as president of the Chemical Warfare Committee; but there was not time for this remarkable innovation to bear fruit before hostilities ceased. General Thuillier was succeeded as Controller of the Chemical Warfare Department by Colonel Harrison, who was to act also as vice-president of the Chemical Warfare Committee. In view of the illness and untimely death of the latter, these duties were fulfilled by Lieut.-Col. (later Brig.-Gen.) H. Hartley, who became controller of the department shortly before the Armistice.

(c) The Separate Development of Supply, 1917–1918.

At the time of the establishment of the Chemical Warfare Department the duties of supplying chemicals, charging them into projectiles or cylinders, and assembling the projectiles with their bursters was still reserved to the Trench Warfare Supply Department. Upon the formation of the Munitions Council in August, 1917, it had, however, been arranged that the Director-General of Trench Warfare Supply should report on questions relating to chemicals through Council Member X, who was concerned chiefly with the supply of explosives. Moreover, a somewhat general responsibility for the production of

chemicals had been assigned to the Controller of the Chemical Warfare Department in November, 1917. He exercised this duty by means of weekly meetings of the Chemical Warfare Committee, at which matters relating to the supply of offensive materials were discussed. The Director-General of Trench Warfare Supply attended these meetings until April, 1918. Responsibility for the supply of poison gas and its charging at chemical works was then assigned to the department of the Ministry concerned with the supply of explosives, while the Gun Ammunition Filling Department took over the duty of inserting the bursters and assembling the shell, and also undertook a certain amount of charging at national filling factories.

This reorganisation was the first step in a general distribution of the duties of the Trench Warfare Supply Department, which were arranged according to the stores concerned, among the main sections of the Ministry, which was organised according to function. It was grounded on a desire to secure towards the production of poison gas the unique experience of the technical experts and chemical engineers attached to the Explosives Supply Department, and to facilitate the use of spare capacity at explosive and filling factories. It was also intended to concentrate control over the raw materials common to explosives and poison gas.

Upon the transfer of these supply functions the Chemical Warfare Department was removed from Group D of the Munitions Council to Group X, thus reporting through the officer concerned with explosive production instead of the officer concerned with design. It was expected that a closer relation between the supply and design authorities would thus be secured. The supply meetings of the Chemical Warfare Committee were abandoned in favour of interdepartmental conferences under Council Member X. Moreover, the Controller of Chemical Warfare became responsible for keeping in touch with chemical warfare in all its stages and for watching the progress of supply, and was given power to initiate supply in anticipation of formal military requirements, subject only to the Minister's approval.[1]

Thus, all stages in research and supply concerning offensive agents and defensive apparatus were concentrated in varying degrees in the hands of the Controller of the Chemical Warfare Department, while close relations with the users of chemicals were established shortly afterwards through the appointment of the Director of Gas Services as president of the Chemical Warfare Committee. This centralisation of control was least complete where the supply of offensive substances was concerned, since, in practice, the supply officers within the Explosives Supply Department retained a large measure of independence. The new and extensive projects set on foot after the reorganisation of April, 1918, chiefly concerned the 1919 campaign and accordingly the results of this partial unification had not had time to manifest themselves before the close of the war.

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[1] M.C. 646.

CHAPTER III.

OFFENSIVE SUBSTANCES: GENERAL METHODS OF SUPPLY.[1]

I. Special Difficulties of Supply.

Peculiar difficulties had to be met in arranging for the supply of offensive substances. Not only was it necessary to develop in the shortest possible time entirely new and intricate industrial processes by translating experimental production in a laboratory to bulk production on a manufacturing scale, but also to be prepared for constant changes in requirements owing to the experimental nature of chemical warfare. Thus, as soon as the requirements for a particular gas had been met, protective measures on the part of the enemy or the employment by the enemy of some new type of offensive substance might lead to the entire abandonment of the use of that particular gas and a demand for the rapid production of others. Moreover, developments in research at home caused still further changes of programme. These fluctuations in demand inevitably resulted, in some cases, in the provision of plant of which little use was subsequently made, so that a considerable expenditure of energy often resulted in a small output, and since the financial resources of the country were strained to the utmost financial sanction for fresh outlay was subject to considerable delay.

II. Sources of Supplies.

(*a*) General Reliance on the Trade.

The demand which arose for chemical supplies for offensive gas warfare was originally met by existing chemical manufacturers. Even before the German attack on the Western Front with lethal gas on 22 April, 1915, the question of the manufacture of S.K. had been considered in order that a stock of bombs filled with a lachrymator might be in readiness for possible use, but no active steps had been taken.[2] After the gas attack, arrangements were made with the Cassel Cyanide Company and other firms for the provision of grenade fillings of an irritant and lachrymatory nature to serve as stop-gaps pending the supply of gas in cylinders, while negotiations with chemical contractors were begun for such supplies of lethal gases as were immediately available, and for the necessary extensions to plant. As the use of fresh chemical substances was determined on, the policy of entrusting their manufacture to various private firms with experience of chemical manufacture continued, and great energy and resource was shown by them. The Ministry encouraged existing firms to make extensions by subsidising new buildings and plant, and in this way benefited

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[1] Hist. Rec./H./1650/10.
[2] See above, p. 2.

by the skilled technical knowledge of manufacturers. Details of manufacturing processes and plans for charging plants were all worked out by the technical and drawing office staffs of the various contractors and the provision and erection of the plants were carried out by their engineering staffs. In all cases an early and rapid production was the first consideration and economies and improvements in working the processes were effected as the work progressed.

(*b*) OTHER SOURCES OF SUPPLY.

With the exception of the Admiralty factory at Stratford, which produced hydrocyanic acid mixtures, and of two French factories, which by arrangement with the French Government supplied phosgene in exchange for chlorine, the British chemical manufacturers remained the sole source of supply until April, 1918. The methods of supply were then reorganised in order to meet constant increases in the importance of gas warfare.[1] With the transfer of responsibility for chemical warfare supplies from the Trench Warfare Supply Department to the Explosives Supply Department, the spare capacity at government explosives factories was adapted for the production of poison gas, and the importation of toxic gases from the United States began somewhat later, when the Americans' productive capacity exceeded their supply of suitable containers.[2]

(*c*) THE CHARGING AND COMPLETION OF PROJECTILES.

Arrangements for the supply of chemical substances for use in grenades, bombs, shells, and cylinders involved also arrangements as to "charging" the projectiles with these substances. This operation in view of its specially technical nature was itself almost a chemical process. The "filling," *i.e.*, the insertion of the bursting charge, and the "assembling" of chemically charged projectiles with their fuses and propellant charges had also to be organised. As it was undesirable to transport lethal substances about the country, the general principle was that charging should be carried out at the works where the substance was manufactured, and contractors were accordingly prevailed upon to undertake this work, an additional reason in favour of this arrangement being that they were already familiar with the nature of the substance to be charged. With the exception of H.M. Factory, Walthamstow, this principle was maintained for the charging of all chemical substances, until the use of H.S. was introduced. This liquid was despatched from the place of manufacture to filling factories controlled by the Gun Ammunition Filling Department, where it was charged into shells, the bursters were inserted and the complete rounds were assembled.

This change of procedure was due partly to the large increase in the use of chemical shells, partly to the introduction of smaller natures of chemical shells which were issued as fixed ammunition, and mainly to the need for making use of spare capacity at the gun ammunition filling factories, and of the experienced staff which controlled them.

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[1] See below, p. 29. [2] X. 236/10. See below, p. 31.

From the first it had been a practice to avoid introducing explosives into the factories where chemicals were made and charged. The only exception at first was the factory at Walthamstow, where S.K. was charged into shells but not manufactured. In the spring of 1916 the insertion of the bursters into chemical shells was undertaken at the Ordnance Factories, Woolwich; but great trouble was experienced with leaky shells, and their filling and assembling was removed almost at once to the Trench Warfare Filling Factory at Watford, pending the construction at Greenford of a special State factory for the purpose. When in 1918 control of these operations was transferred to the Gun Ammunition Filling Department, both the charging and the filling of shells were undertaken at the specially erected factory at Chittening, and also in the National Filling Factories at Banbury and Hereford, while the assembling of the complete rounds of smaller natures was carried out at the National Filling Factory at Hayes, as well as at Banbury and Hereford. Part of the National Filling Factory at Morecambe, which had been destroyed by fire, was also rebuilt for a similar purpose. This concentration within State factories of the operations involved in completing chemical ammunition accorded with the general policy of maintaining State control over the handling of explosives.[1]

(*d*) Plants provided for Chemical Supplies.

By April, 1918, about seventy different plants had been erected for the manufacture of chemical substances, for charging projectiles with the service mixtures and for filling and assembling chemical shells, bombs, and grenades. The plant for making offensive chemicals and their materials, which had been established under some sixteen contractors by this date, was capable of a weekly output of 2,693 tons. By far the greater part, *i.e.*, plant having a total capacity of 2,172 tons weekly, was erected and operated by the three chief bleach and chlorine makers of the country, *viz.*, the Castner Kellner Company, the United Alkali Company, and the Electro-Bleach and Bye-Products Company.[2] The only undertakings which were established as national factories during this period were the naval factory for J.L. and V.N. production at Stratford, the phosgene charging plant erected at Calais, and the two factories for filling and assembling chemical projectiles at Greenford and Watford. The administration of three factories had, however, been taken over by the supply department. These were a depôt at Bucknall for evacuating and cleaning cylinders, certain C.G. plant previously operated by Messrs. Ardol, Ltd., at Selby, and the Walthamstow factory for charging S.K. into shells, bombs, and grenades. The greater part of the projects for extending plant for offensive substances after April, 1918, took the form of new State factories or the conversion of the capacity originally established for explosive manufacture.[3]

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[1] The details of the work of charging, filling and assembling are narrated below at p. 54.

[2] See Appendix IV.

[3] See below, p. 29.

III. Relations with the Trade from 1915 to April, 1918.

(a) CONTRACT PROCEDURE.

Owing to the novelty of manufacturing processes, it was impracticable to lay down beforehand the detailed terms of a contract. The method generally adopted was to approach suitable contractors when a demand arose for a certain gas and, in instructing them to begin work, to fix provisionally a maximum of expenditure. The formal contract was completed later. In May, 1916, a number of new contracts had to be made to meet the new demand for lethal substances in artillery shell. They involved both extensions to existing plants and the provision of entirely new plants.

The same general principles governed these and similar contracts of later date. The Ministry was responsible for the capital cost, paying the contractors the cost of plant and necessary alterations and extensions of buildings, plus 10 per cent. for supervision and general charges, a maximum figure which was not to be exceeded being stated at the outset for the cost. Repairs and replacements were paid for by the Ministry on certificates signed by a representative of the Ministry stationed at the factory. A contract for output at a fixed rate was arrived at, and raw materials which it was necessary to provide from other sources than the contractors' own works were supplied by the Ministry as free issues. The plant and its output were to be used solely for the purposes of the Ministry of Munitions in each case. The contractors were indemnified by the Ministry against risks arising from the work. Some time elapsed before these contracts were actually signed. Early in 1916 nearly all the plants supplying the new gases were scheduled as controlled establishments under the Munitions of War Act and the lack of any pre-war standard in such production made any financial decision a matter of peculiar difficulty. The consequent delays in the completion of the formal contracts did not, however, interfere with supply, as the contractors, acting on the original instructions given them, provided and erected the plants and operated them as required.

(b) SUPERVISION OF CONSTRUCTIONAL WORK.

At the end of 1916 the Munitions Works Board was set up for the purpose of approving all proposals for constructional work to be done by or for the Ministry and for exercising a general supervision over the carrying out of this work, but chemical plants for poisonous gases ranked in a special category on account of the unusual and experimental nature of the work. The Chemical Section accordingly obtained authority to contract out of this procedure and made its own arrangements to supervise the erection of new chemical plants. A system was established for checking the various materials used and for certifying, from time to time, payments on account of work done, subject to the examination and audit of the books of the companies by the Finance Branch of the Ministry.

In the course of supervising the construction of new plant and extensions at contractors' factories, the chemical supply officers were able to accelerate the work by facilitating arrangements for supplies of building materials, by obtaining general priority certificates, usually

of a high-class grade, both for the materials needed for new works and for maintenance, and by negotiating with the Labour Supply Department and the dilution of labour authorities for a sufficient supply of suitable labour both for construction work and for the processes of manufacture. Even the high priority granted to lethal gas production failed, however, to secure an adequate supply of efficient labour, with the result that delays occurred.

The Department kept in close touch with the contractors by means of technical representatives stationed at the various works. These representatives reported weekly to headquarters on the progress of construction work, checked and certified expenditure on labour and materials, and by hastening on deliveries of materials, etc., generally expedited the completion of the work.

(c) INSURANCE.

The manufacture of lethal and lachrymatory substances called for special arrangements as regards the insurance of buildings and plant and also of workpeople. In the case of contractors manufacturing P.S. and, therefore, having picric acid stored in the works, it was decided to issue requisitions under the Defence of the Realm Act so that in the event of an accident any claims might be argued before the Defence of the Realm (Losses) Commission, for the existing policies of the contractors did not cover explosives risks, and it was found that insurance companies would require very large premiums to cover these. In order to meet a claim put forward by one firm manufacturing P.S. for a guarantee against loss of profits, the output was requisitioned and manufacture was abandoned as soon as an alternative capacity had been established.

Generally speaking, while no fire insurance was taken out by the Government for its own chemical warfare buildings, it was prepared to pay insurance premiums on additional policies taken out to cover increased risks by the owners of buildings loaned or let to the Department.[1]

In the case of minor accidents occurring to workpeople from poisoning, since the secrecy of the processes employed precluded firms from taking out insurance policies, it was arranged that each contractor should deal in the ordinary way with cases which came under the Workmen's Compensation Act, such claims being submitted to the Legal and Finance Branches of the Ministry for decision.

Accordingly the following clause was ultimately inserted in all contracts for poisonous substances, in order to cover all claims by workpeople and third parties:—

> "Subject to your complying in all respects with the directions given you from time to time by the Representatives of the Ministry of Munitions, with a view to greater security, the Minister will indemnify you in any claim arising from poisoning due to any materials used or to be used, in providing the said output, and so far as the same is not covered by any policy of insurance taken out by the Company."

[1] HIST. REC./H./1650/4.

IV. Inspection of Chemicals.

As regards inspection of chemicals, it was not at first possible, owing to the experimental nature of the work, to lay down definite specifications under which inspection might be carried out. Later, as the nature and properties of the substances became more fully known, specifications were drawn up, and in June, 1917, it was arranged that the Chemist, Inspection Department, should undertake inspection, central laboratories to which samples for analysis were sent being erected for the purpose.

V. Control of Chemical Materials.

The amount of control exercised in regard to chemical materials increased with the general growth in the demand. Control over export was effected from the first in conjunction with the War Trade Department, the Chemical Advisory Committee giving their technical opinion as to the desirability or otherwise of exporting chemicals, and the Chemical Supply Section dealing with the question from the point of view of sufficiency of supply. In order to regulate supplies for essential war purposes and to keep down prices, the Chemical Supply Section exercised an informal general control. This was at first effected by friendly negotiations with the contractors. Later, as supply became of increasing difficulty and the regulation of consumption grew in importance, formal control was taken over two of the most important materials. Thus chlorine supply was regulated only by means of negotiations with makers and users until September, 1918, when, with the enormous increase in the demand for this material, it was considered necessary to control chlorine and its compounds under the Defence of the Realm Act.[1] Again, in October, 1917, increased demands for acetic acid and speculation in the American market led to the issue of an acetic acid control order.[2] The question of safeguarding supplies of sodium cyanide called for special consideration when the use of hydrocyanic acid mixtures was introduced into chemical warfare, and for this purpose an interdepartmental Cyanide Committee was appointed.[3]

Generally speaking, where it was necessary to supply firms with raw materials, these issues were made free until after the change in organisation in April, 1918, when an effort was made to do away with free issues, as these did not stimulate economy in the use of raw materials.

VI. General Policy (April—November, 1918).

(a) THE USE OF STATE FACTORIES.

With the administrative reorganisation which took place in April, 1918, the general policy as to chemical supplies was changed in certain important respects. The officers of the Explosives Supply Department, who then became responsible for the supply of poison gas, had

[1] See below, p. 38. [2] See below, p. 40. [3] See below, p. 46.

relied to a very remarkable extent upon large national factories for the production of explosives. They had had unique experience in constructing and managing these enormous works and at this juncture reductions in the explosives programme were making available both men and plant for a new class of work. Hence, though for the most part they maintained existing contracts, yet on the whole they provided for the rapidly increasing poison gas production rather by the adaptation of existing national factories and the erection of new ones than by entering into further agreements with contractors. Thus H.M. Factory, Avonmouth, which had originally been planned in part for the production of picric acid, became the principal producer of H.S., while the building began in the spring of 1918 of H.M. Factory, Langley, as an agency factory for the manufacture of carbon tetrachloride, which was needed as a diluent in the manufacture of H.S. H.M. Explosive Factories at Sutton Oak and Ellesmere Port were also converted to gas manufacture (D.A. and D.M. respectively), as was also a factory at Rainham Ferry, which became a national factory for the production of T.A. The nitro-cotton nitration house at H.M. Explosive Factory, Queen's Ferry, which had been closed down, was also utilised in connection with arsenic compounds. Owing to the unsatisfactory conditions obtaining in the chlorine liquefaction and phosgene plants of Messrs. Electro-Bleach, these were taken over in August, 1918, and became H.M. Factory, Middlewich, the output of the factory being thereby nearly doubled. Plans were also made shortly before the Armistice for the erection of a national chlorine and phosgene factory at Avonmouth, as part of a scheme for rendering the country independent of C.G. supplies from Calais, where output was much hampered by aircraft attacks. At the same time the authorities responsible for gun ammunition filling, to whom the duty of charging, filling and assembling had been transferred, arranged that H.S. charging and filling should be carried out at a new State factory erected at Chittening. The use of spare capacity at the National Filling Factories has already been described.[1]

(*b*) NEW CONTRACTS.

Efforts were, however, made to assist and stimulate firms who had already some knowledge and experience of the substances to be handled, and some fresh contracts with chemical manufacturers were arranged. The main difference in procedure was the attempt to eliminate free issues as a means of economising materials. A limited supply of H.S. was purchased from Messrs. Levinstein, who on their own initiative had carried out work on its production, while sulphur chloride for H.S. and monochlorbenzene for D.A. manufacture were supplied by the United Alkali Company. Arrangements were made during 1918, in addition to the scheme for a national chlorine factory at Avonmouth, for extensions to the works of Messrs. Castner Kellner and to the United Alkali Company's chlorine plant and for the erection of phosgene plant at Widnes by the last-named company. These

[1] See above, p. 26.

extensions, for which negotiations had already been begun, were to be in the nature of assisted contracts, the Government contributing 80 per cent. of the capital cost. Messrs. Castner Kellner's K.J. plant at Runcorn was also extended to reach a capacity of 60 tons per week, the Government contributing the whole of the cost.

(c) OVERSEAS PURCHASES.

In April, 1918, an Inter-Allied Commission for Chemical Warfare Supply, consisting of representatives of Great Britain, France, and the United States, was formed with a view to co-ordinating the resources of these three countries. In America, the production of chemical substances was far ahead of the supply of suitable containers, while in Great Britain the charging capacity was likely to exceed the substances available, until the new chlorine plants came into operation. Accordingly, chlorine compounds and poison gas based on chlorine, *e.g.*, sulphur chloride, C.G., P.S., and H.S., were imported from America. The first shipments arrived in August, 1918, and by November, 500 tons of chemicals and 2,400 tons of toxic gas had been shipped.[1]

VII. Summary.

A table showing the output of the principal chemicals which were manufactured for war purposes and for which new plants were provided or existing ones extended is given in Appendix V.

Of the total of 92,000 tons there were about 21,000 tons of liquid chlorine, which was used both for charging and also as an intermediate product, 21,000 tons of other chemicals used for charging, and 50,000 tons of other intermediate products, by far the largest of these being bleaching powder, which accounted for about 93 per cent. of the whole. Of the 21,000 tons of chemicals for charging, about 6,000 tons was phosgene provided by France, and in addition to the tabulated figures 2,900 tons of chemicals for use as intermediates or for charging were shipped from the United States in the closing months of the war.

The cost of production of the chemicals shown in the table amounted approximately to £6,500,000, exclusive of the cost of projectile charging, filling, and assembling.

The total costs of the plants and buildings provided amounted to approximately £4,500,000, of which the contractors contributed approximately 25 per cent. and the remaining 75 per cent. was borne by the Department. The large proportion of the State expenditure was due to the fact that comparatively little of the plant had any post-war value. Much of it was not well suited for adaptation for other purposes and was ultimately sold as scrap.

When the Germans introduced chemistry into war, they relied upon the fact that their dyestuff monopoly would give them a great advantage over the Allies in the production of toxic substances, and with one insignificant exception the whole of the chemical warfare products used by Germany in the course of the war were made by the

[1] (Printed) *Weekly Reports passim.*

Interessen Gemeinschaft, the great combine of the German aniline dye manufacturers. They obtained their requirements of any new gas speedily by making use of suitable existing plant, wherever it might be. Thus the several steps in the production of a toxic gas were generally carried out in different factories; *e.g.*, since one factory possessed a plant suitable for the manufacture of thiodiglycol, this intermediate product for H.S. was manufactured there, though the final product was prepared at another factory.[1]

In this country, when a new gas had to be made, plant had in nearly every case to be specially erected for the purpose, for the capacity of the comparatively small dye industry was fully taken up in producing necessary dyes and high explosives. Incidentally also, great strides were made in general manufacturing practice, particularly in the quantities of chemical materials used for the production of the final products. Some idea of this advance may be gained from the table of consumption figures recorded in Appendix VI below. In the chapter which follows the methods adopted for providing each specific substance will be considered in detail, approximately in the order in which they came into service use. A close study of these arrangements and their results reveals the great enterprise and the almost superhuman efforts which ultimately placed Great Britain on an equal footing with her enemies in regard to chemical warfare.

[1] It is interesting to note in this connection, the British reasons for abandoning the scheme for manufacturing H.S. by this process. See below, p. 51.

CHAPTER IV.

OFFENSIVE SUBSTANCES: THE DETAILS OF SUPPLY.

I. Chemical Grenade Fillings.

Activity with respect to grenades charged with obnoxious chemicals began in May, 1915, when their speedy supply was demanded in order that they might be used as a stop-gap pending the supply of cylinders containing gas.[1] Extracts of capsicum and chillies were prepared by Messrs. Boake Roberts & Company, Stratford, and early in May they began filling grenades with capsicine mixed with sulphur dioxide and capsicine mixed with carbon bisulphide. In the following month (18 June) the Hammersmith Distillery Company also started filling grenades with the latter mixture, but after they had been working about three weeks and had filled 3,000 tins the demand for such grenades ceased and this work was closed down. The number of tins which Messrs. Boake Roberts filled with the first mixture was 22,180 and with the second mixture 16,650.

Charging with the experimental mixture called Hillite, consisting of capsicine and magnesium carbonate, was undertaken at this time by another firm, the County Chemical Company, Birmingham. Upon the re-introduction of the Hillite grenades (No. 33) in 1918, the charging of the grenades was carried out at the Walthamstow National Factory.

The lachrymatory substance S.K. (ethyl iodoacetate) which survived as a grenade filling was manufactured by the Cassel Cyanide Company at Glasgow. Although this firm did a certain amount of experimental filling they were unable to undertake the charging of grenades in bulk, and Messrs. Baird & Tatlock, who provided the glass containers employed in the early types of grenade, were accordingly prevailed upon to do it at Walthamstow, where they had already been charging glass containers with sulphur chloride and bromine. Early in 1916 their work with S.K. grenades was largely superseded by the charging and assembling of lachrymatory and lethal shell; but the charging of S.K. grenades, which by this time were of cast-iron and spherical in shape (No. 28), was resumed in June, 1917, and the Walthamstow factory also charged the K.J. grenades issued during the autumn.

II. Chlorine (Red Star).

Chlorine was an essential element in British poison gas activities. Not only was it used either by itself or mixed with some other substance in "cloud" attacks, but it also entered into the manufacture of practically all chemical fillings used for service. Chemical warfare, therefore, made great demands on the capacity of the country for chlorine manufacture.

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[1] See above, p. 4.

At the outbreak of the war, chlorine was manufactured by several processes. A usual method was by the action of oxidising agents on hydrochloric acid, the oxidising agent being either an oxide of manganese (Weldon process) or atmospheric oxygen (Deacon process). The hydrochloric acid used was obtained as a bye-product in one of the stages of the Leblanc process for converting common salt into sodium carbonate. The bulk of the chlorine manufactured by these processes was for use as a bleaching agent. It was converted into bleaching powder or "chloride of lime," by being brought into contact with lime, this being used as a convenient absorbent for the chlorine. Bleaching powder should contain about 36 to 37 per cent. of "available" chlorine.

Chlorine was also made electrolytically from brine, a process which is now superseding all others. Chlorine so made is suitable for liquefaction. Before the war liquid chlorine was prepared for use in colour-making works and for treatment of gold ores.

In May, 1915, when it was decided to use gas in retaliation, it was found that the only plant for supplying liquid chlorine was that belonging to the Castner Kellner Company, Runcorn, whose electrolytic process for the decomposition of brine produced the purest chlorine for liquefaction, the capacity of the plant being about 5 tons of chlorine per week. Early in June a meeting of the chlorine manufacturers was called in order to ascertain the total capacity of chlorine plant in the country and the possibilities for increasing the liquefaction plant. One other manufacturer employed the electrolytic process using brine, namely the Electro-Bleach and Bye-Products Company, Middlewich, but had no liquefying plant. Of the four other chlorine manufacturers, two (The United Alkali Company and the Salt Union) employed the Deacon and Weldon chemical processes which produced chlorine which was converted into bleaching powder, and two (Messrs. Brunner Mond and Messrs. Albright & Wilson) produced chlorine by the electrolysis of zinc chloride, but in comparatively small quantities.

As a result of the meeting in June, the Castner Kellner Company, who produced the largest quantity of chlorine electrolytically, were instructed to proceed with an extension of their liquefying plant up to 150 tons per week and to arrange for charging the liquid into cylinders. A contract, which was signed in August, 1915, provided that the initial cost and the maintenance of the plant would be borne by the Ministry. The plant was to be devoted solely to the execution of orders for the purposes of chemical warfare and deliveries were taken as from 26 July, 1915.

The price of the liquid chlorine charged into cylinders provided by the Government was to be £18 per ton. Should the requirements of the Department interfere with trade contracts of the company for bleaching powder, the Department was to provide the quantities of bleach required from other sources at a fixed price of £5 10*s*. per ton. Provision was also made whereby the company could take over the plants at an agreed value, on production being no longer required by

the Government. It was owing to the fulfilment of this contract that the British were able to deliver their first gas attack on 25 September, 1915.

At the end of 1915 deliveries to the armies were suspended, but large supplies were despatched to the French Government, in addition to the supplies sent to the Calais phosgene factory.[1]

In April, 1916, the decision to use chloropicrin (P.S.) necessitated the provision of large quantities of bleaching powder, since it was then considered that 1 ton of P.S. required approximately 10 tons of bleaching powder for its manufacture. As this would probably interfere with the trade supplies of bleaching powder, the matter was discussed at a meeting of the Commercial Advisory Committee on 18 May, 1916. It was considered that additional plant for liquefying chlorine should be provided in order to avoid any possibility of default on the part of the Castner Kellner Company in respect of its trade contracts for bleach. The Electro-Bleach Company was accordingly instructed to provide a liquefying plant for 50 tons per week, and the United Alkali Company was directed to provide a new electrolytic plant at Gateshead for an output equivalent to 125 tons of bleach per week, and also a liquefying plant for 50 tons per week. The work was put in hand and contract negotiation began. Considerable discussion ensued as to the price to be paid for the bleaching powder for P.S., and meantime, in order to safeguard the supplies, it was decided to requisition under the Defence of the Realm Act such quantities as were necessary for the manufacture of P.S. and also the quantities of liquid chlorine required. Requisitions were accordingly issued to the three manufacturers (the Castner Kellner Company, the United Alkali Company, and the Electro-Bleach Company) on 17 August, 1916.

The price of bleach before the war had been about £5 10*s*. per ton naked at works, but the prices finally agreed upon naked at works were £7 10*s*. per ton for bleach by the electrolytic process and £10 per ton for bleach by the chemical process. This difference in price was grounded on the fact that in war-time the latter methods of production were the more expensive owing to the curtailing of the market for the other products connected with the process, the sale of which normally enabled the chemical producers to compete with the electrolytic producers. Subsequently Messrs. Castner Kellner undertook, however, to supply the quantity of bleach allotted to them at £7 10*s*. per ton including packages, this price being based on the price of gaseous chlorine at £15 per ton. Arrangements were then made for the three contractors to supply the quantities of liquid chlorine and bleaching powder required.

About this time, in October, 1916, considerable anxiety arose among bleach users lest deliveries on their contracts should be suspended on account of the Government requisitions, and the suggestion was made that the whole of the chlorine manufacture should be controlled. Colonel Alan Sykes, on behalf of the Bleachers Association, Ltd., made inquiries as to what steps could be taken to assist the Government by

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[1] See below, p. 42.

curtailing the quantities of bleach for trade purposes, and as a result a Bleach Users Committee representing the Bleachers Association, the Dyeing Trade, the Calico Printers Association, and the Paper Trade, was formed by the Minister. In order that the position might be reviewed, all chlorine manufacturers were asked to render particulars of the weekly pre-war and current requirements for Government and trade purposes and to state the capacity of their works. The returns, which were rendered in terms of bleach, showed a pre-war output of 1,943 tons per week, of which about 33 per cent. was exported. The output of bleach at the time was reduced to 1,782 tons per week, of which about 20 per cent. was supplied as liquid chlorine. The requirements per week were 2,539 tons (*i.e.*, 1,475 tons for the Government and 1,084 tons for the trade) and the total capacity was just over 2,000 tons, leaving a deficit of about 500 tons. Accordingly all exports were prohibited except under permit, although it was desired to continue export if possible, the Stationery Office was requested to arrange that the use of paper requiring double bleach should be discontinued as far as possible, the War Office was asked whether the use of chloride of lime could not be considerably curtailed, and the Explosives Supply Department was asked to recommend the use of unbleached cotton waste for gun-cotton. It was hoped by these suggested economies to reduce the deficiency to about 300 tons per week, and to meet this deficiency the Castner Kellner Company were instructed to put down additional plant to provide chlorine equal to another 300 tons of bleach per week, while at the same time the Electro-Bleach Company were instructed to provide the equivalent of a further 100 tons per week. Instructions were also given to the United Alkali Company to duplicate their Gateshead electrolytic unit. By these arrangements the total weekly capacity of the country would be increased to 2,600 tons. In addition to these arrangements, proposals for the erection of new chlorine plant were received from Lord Lurgan, who suggested the use of the new Jenkins electrolytic cell; but this method of manufacture was still in an experimental stage, and after investigation his proposals were not adopted. A scheme for manufacture by means of the Jenkins cell, which had been negotiated with Messrs. Morris & Company, in September, 1916, was accordingly abandoned by the Department. Nevertheless, Mr. Morris proceeded with his plant, and having produced liquid chlorine in March, 1918, he entered into an agreement with the supply department for about 10 tons per week.

At a meeting of the Bleach Users Committee on 7 December, 1916, the necessity for curtailing the trade requirements until the new plants came into commission was discussed, and the Chairman (Colonel Sykes) undertook to ration the trade through the Committee, who were not in favour of a scheme of control then laid before them. In view of this arrangement, and the assurance given by manufacturers to notify the Chemical Supplies Branch of any large orders received from other departments, it was decided not to make any order under the Defence of the Realm Act. Nevertheless, weekly output returns were obtained from the contractors. Other Government departments

also agreed to this arrangement and permit letters were written to contractors by the Chemical Supplies Branch as demands came forward, the prices being fixed for all Government orders at the contract prices prevailing.

In January, 1917, increased provision for bleach and chlorine supplies was urged, and on 3 January the Minister decided that the total producing capacity should be brought up to 3,500 tons.

Following on this decision arrangements were made to provide the extra 900 tons required by means of three distinct projects. The Castner Kellner Company were to construct an entirely new unit including new gas-producing plant, bleaching chambers and caustic evaporators for 600 tons per week. The Electro-Bleach Company were to install a completely new power and cell unit for a further 100 tons per week, in order to balance their liquefying plant. The United Alkali Company were to duplicate the unit at Gateshead making 125 tons per week and to provide a new unit making 100 tons per week at their St. Helen's Works, obtaining the power from the St. Helen's Electric Corporation.

These three proposals involved an approximate outlay of £600,000. Owing to the protracted nature of the negotiations, little real progress was made until March, 1917. The change of military policy in regard to offensive substances, which was notified in the following May,[1] was met by a decision to curtail the chlorine extensions then in progress. As the construction of the plant at Messrs. Castner Kellner's works was not far advanced the contract with this company was cancelled.

The formalities involved in cancelling this agreement were scarcely complete, when an entire revision of the chlorine supplies was necessitated by the demands for large quantities of H.S. which were received in August and September, 1917.[2]

The chlorine required for the process of H.S. manufacture then proposed was needed in liquid form to facilitate transport and the electrolytic process of manufacture was necessarily chosen in arranging for an extension of the chlorine programme. By this new demand an additional 1,300 tons of chlorine (in terms of bleach) per week would be required and it was proposed to meet it by two projects. The one was for the resuscitation of the Castner Kellner contract for 600 tons together with an additional 200 tons, making 800 tons in all, with a corresponding extension to the firm's liquefying plant, raising its capacity from 150 tons to 545 tons. The other was to instal entirely new electrolytic units at the United Alkali Company's works, Widnes, equal to 500 tons of bleach per week, and in addition to provide liquefying plant for 150 tons per week. The cost of these extensions was estimated at £990,000. Protracted negotiations as to the terms of the agreements followed and the contracts were eventually signed on 10 December, 1917, and in February, 1918, respectively. The Government contributed 80 per cent. of the capital cost of the new plant. The United Alkali Company's new liquefying plant at St. Helen's commenced output in November, 1918.

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[1] See above, p. 8. [2] See pp. 9 and 49.

At the end of December, 1917, the H.S. programme was reduced by one-third, but in view of the essential part played by chlorine in the production of all chemical warfare supplies, and on the ground that chemical warfare was certain to advance rather than recede, no alterations were made in the chlorine contracts already placed.

The following table shows the three phases through which the chlorine extensions passed prior to the change in organisation in April, 1918.

CHLORINE AND BLEACH ESTIMATES (IN TERMS OF BLEACH).

December, 1916.	Tons per week.	June, 1917.	Tons per week.
Pre-war capacity	2,100	Pre-war capacity and extensions authorised ..	3,500
Extensions authorised ..	1,400	Less Castner Kellner Contract cancelled	600
	3,500		2,900

January, 1918.	Tons per week.
Pre-war capacity and extensions in progress..	2,900
Additional extensions	1,280
	4,180

The very large increases contemplated early in 1918 for the 1919 gas programme made the need for a still greater chlorine capacity apparent, and instructions were given in April, 1918, to double the existing output. Extensions in progress were hastened, pending their completion large quantities of chlorine compounds and toxic gases were purchased from America, and a scheme for a national chlorine factory at Avonmouth was developed. This last scheme was not definitely authorised before the signing of the Armistice.

On 15 August, 1918, the Explosives Supply Department, which had become responsible for the production of poison gas, took over the liquefying plant erected by Messrs. Electro-Bleach at their works at Middlewich, together with their phosgene plant, and thenceforward controlled and operated them as H.M. Factory, Middlewich, by this means increasing the output. They worked as far as possible in cooperation with the Company, who supplied the chlorine gas for liquefaction.

Prices of bleach and liquid chlorine were raised by the manufacturers after notice given in March, 1918. In the poison gas manufacture of 1918, chlorine was most needed in liquid form and bleach was only used for making P.S., but the big chlorine firms could get a far higher profit for bleach than for liquid chlorine, and in consequence their output of the latter was relatively small. Hence, in September, 1918, the Explosives Supply Department took formal control of chlorine and chlorine compounds. By the Chlorine and Chlorine Compounds Order, 1918, issued on 6 September, the sale or purchase of any chlorine or bleaching powder at a price exceeding

the schedule price was prohibited. The maximum price fixed for liquid chlorine was 6*d*. per lb., and for bleaching powder £15 per ton. Licenses were required for the production, use and sale of chlorine.[1]

III. Ethyl iodoacetate (S.K., K.S.K.).

From the date of the first schemes to use S.K. as a lachrymator in retaliation for the German gas attack in April, 1915,[2] manufacture of the liquid was undertaken solely by the Cassel Cyanide Company, Maryhill, Glasgow, under the direction of Dr. G. T. Beilby, who was a member of the War Committee of the Royal Society and also a director of the Company.

Pending the construction of the factory at Walthamstow, the Company undertook a certain amount of charging. The original plant for S.K. manufacture was largely extemporised from old materials and vessels which the Company had in their possession. The first contract covered the initial expenses incurred by apparatus and output from the commencement in May to the end of December, 1915. A second contract covered the disbursements of the Company up to 30 June, 1916, for the manufacture of about 12,000 gallons per month. When in June, 1917, the decision to increase output was taken, it was found that the old plant was in such a bad state of repair that it would be necessary to design and erect an entirely new plant, and, when this was working, to scrap the old one. Accordingly a contract was made in October for a new plant of a capacity of about 50 tons of pure S.K. (*i.e.*, K.S.K.) per week. The Company designed and erected the plant and the State bore the capital cost up to £15,000. The plant remained the property of the Ministry. The price of the pure S.K. was to be settled by mutual agreement when the plant was working. Output began by April, 1918.

Raw materials were delivered to the Cassel Cyanide Company as free issues. For this purpose the Ministry first obtained chloracetic acid from the Castner Kellner Company at 1*s*. per lb., the price fixed on 6 May, 1916. Subsequently, when further quantities of S.K. were required, it was arranged to put down additional plant at the United Alkali Company's works, Widnes, to provide output of 18 tons per week of mono-chloracetic acid, and also 10 tons per week of glacial acetic acid. The expenditure sanctioned for these two contracts with the United Alkali Company was not to exceed £39,620 and £6,580 respectively, and the Company agreed to put down these plants and to make arrangements with the Inland Revenue authorities for a substantial writing off. As, however, H.S. came into use before these plants were completed, further work was stopped.

The entry of America into the war occasioned considerable speculation in the United States in acetate of lime, glacial acetic acid, and acetic acid of all strengths, and in August, 1917, the United Alkali Company experienced difficulty in importing sufficient quantities of acetate of lime for acetic acid. The Aeronautical Supplies Department were also requiring considerable quantities of glacial and high-

[1] See Appendix VII.

[2] See above, p. 2.

strength acetic acid, and a conference was accordingly held, attended by the Director of Propellants Supplies, the Director of the Chemical Section, and a representative of the Aeronautical Supplies Department, at which it was decided to purchase from Canada and the United States all possible quantities of glacial and high-strength acetic acid, and to make arrangements to control the sale and purchase of these acids in this country. A control order dated 21 September, 1917, was accordingly issued by the Ministry, prohibiting the sale or purchase of glacial acetic acid and acetic acid of 60 per cent. strength and upwards, except under licence from the Director of the Chemical Section of the Trench Warfare Supply Department, and on 2 October this order was extended to include all strengths of acetic acid.[1]

Responsibility for executing this order was shortly afterwards transferred to the Propellants Branch of the Explosives Supply Department, which was already controlling the output of other products of wood distillation.[2]

The whole of the quantities of sodium iodide required were supplied by a single firm who provided the necessary plant and carried out the work of converting iodine into sodium iodide under supply contracts, the iodine being delivered to them by the Department, who purchased it through an agent.

The necessary quantities of alcohol were obtained through the Propellants Branch of the Explosives Supply Department.

IV. Sulphuretted Hydrogen (Two Red Star) and the Green Star Mixture.

As a result of a meeting of the Scientific Advisory Committee which was held on 10 August, 1915, Messrs. Chance & Hunt, who had been carrying out experiments in conjunction with Professor Cadman, were instructed to erect plant for the supply of liquid sulphuretted hydrogen in bulk. The work was immediately put in hand and the plant, which had a capacity of 20 tons per week, was ready by the middle of October, 1915.

Under the agreement, which was signed on 27 October, Messrs. Chance & Hunt were to remove and re-erect certain compressing and refrigerating plant which had been requisitioned under the Defence of the Realm Act from a firm of chemical manufacturers at Walsall. The plant was to be erected under the direction and superintendence of Professor Cadman and was to be capable of producing an output of liquefied sulphuretted hydrogen at the rate of 20 tons per week. The price was fixed at £12 per ton. Foundations and all buildings were to remain the sole property of Messrs. Chance & Hunt, who were to have the option of purchasing from the Minister the requisitioned plant or any other plant or accessories provided by the Minister. Full indemnity was given to the contractors against any injury or damage sustained by them. The sulphuretted hydrogen was charged by the contractors into a type of cylinder similar to that used for chlorine.

[1] Vol. VII, Part IV, Chap. IV. [2] *Ibid.*

In consequence of certain field trials made on 11 December, 1915, a certain proportion of carbon bisulphide was mixed with the sulphuretted hydrogen in order to make the gas heavier and a favourable report on further experiments led to some extensions to the plant at Oldbury. By February, 1916, about 2,000 cylinders were filled and sent to France, some containing sulphuretted hydrogen alone, and some a mixture of sulphuretted hydrogen and carbon bisulphide, usually in the proportions of approximately 90 per cent. of the former to 10 per cent. of the latter.

In the spring of 1916 when the decision was made to use, "Green Star," a mixture of 35 per cent. sulphuretted hydrogen and 65 per cent. chloropicrin (P.S.) in cloud gas attacks, it was arranged to put down a further plant for liquefying sulphuretted hydrogen at the works of the United Alkali Company, Widnes.

The new plant began production in September, 1916, and after some small initial difficulties had been overcome the results achieved were extremely satisfactory, and the output was sufficient to meet all the sulphuretted hydrogen requirements. Accordingly in November, 1916, it was decided, since it was unnecessary to work both plants, to shut down the plant at Messrs. Chance & Hunt's works, and to carry out all the Green Star manufacture and charging at Widnes. Cylinders were first charged with the necessary quantity of P.S. at the works where this substance was made. The air was then evacuated from the cylinders which were sent to the sulphuretted hydrogen factories for the completion of the charge. The plant at Messrs. Chance & Hunt's works was maintained for a time as a stand-by and was eventually closed down in November, 1917, as a result of the abandonment of the use of sulphuretted hydrogen.

In consequence of the decision to abandon the use of Green Star, the cost of the provision of plant and the output of sulphuretted hydrogen and Green Star was rendered a fruitless expenditure of about £250,000.

V. Phosgene (C.G. or Carbonyl Chloride).

When the use of phosgene was mooted at the Boulogne Conference in June, 1915, manufacture in bulk had never been undertaken in Great Britain.[1] The French method was a secret process which had been worked out before the war by M. de Laire, and involved the use of pure carbon monoxide. The United Alkali Company prepared C.G. in their laboratory and were instructed by the Scientific Advisory Committee in July, 1915, to go further into the matter with a view to providing British plant. At the same time the French authorities were approached as to whether the Usine de Laire near Calais, where there was a disused phosgene plant, might be taken over by the British army and enlarged, but this factory was required for the use of the French. Further negotiations ultimately resulted in an arrangement with the French Government for the exchange of chlorine from England for phosgene from France in the proportion of two to

[1] See above, p. 3.

one. In the meantime, upon a recommendation of the Scientific Advisory Committee at the beginning of September, a contract dated 28 October, 1915, was made with the United Alkali Company for erecting and operating a plant at Gateshead capable of turning out 6 tons of phosgene a week. This was increased later to 10 tons per week, the carbon monoxide being obtained from producer gas. The plant was erected and began production early in January, 1916, but owing to initial difficulties regular output was delayed for some two or three months.

The arrangement made with the French in November, 1915, whereby for every ton of phosgene supplied by them, the British were to supply two tons of chlorine, was at first expected to come into operation by 1 December, and it was originally considered that the Usine de Laire would undertake to do all the charging of the White Star Mixture into cylinders. Deliveries did not, however, commence so early, and a representative of the Chemical Supply Section who was sent to Calais at the end of January, 1916, found that it would be necessary to make separate arrangements for charging. By the first week in March, plant capable of charging 3,400 cylinders (*i.e.*, 100 tons of mixture) per week was ready, but the French authorities were hampered by the shortage of labour, and requested that English workmen might be sent to Calais to undertake this work. Some 20 to 30 civilians were sent over hastily, but this arrangement did not work well, and the civilian labour was finally replaced by a military working party from the Special Brigade, and from that time to the end of the war the work of filling cylinders, bombs, and projector drums was carried out at Calais by military labour under the direction and supervision of a representative of the Chemical Supply Section.

Up to April, 1916, no formal agreement had been drawn up between the French and British authorities, but the failure of the French to supply the promised quantities made it necessary to regularise the whole matter. Accordingly, as a result of a conference arranged between the French and British Chemical Sections in Paris, an agreement was made on 5 June, 1916, whereby the British Government would receive 160 to 200 tons of C.G. per month at the Usine de Laire, Calais, the C.G. being produced there or failing that sent from another factory at Lyons.

For the first 160 tons of C.G., 200 tons of chlorine were to be sent, but for subsequent amounts of C.G. the proportion was to be 10 tons of C.G. from Calais to 16 tons of chlorine, or 10 tons of C.G. from Lyons to 20 tons of chlorine.

The price charged to the British Government for the first 400 tons of C.G. was to be at the rate of 2·25 francs per kilo and subsequent quantities at the rate of 0·75 franc per kilo. This agreement continued in force until September, 1916, when another agreement (signed 17 December, 1916) was made for a period of three months to 31 December, 1916. This agreement provided for 200 tons of C.G. from Calais and 40 tons from Lyons also to be delivered at Calais, and in return for this 240 tons the British undertook to supply to the French Government at Calais 360 tons of chlorine per month. The prices for the C.G. were

to be 0·75 francs per kilo from Calais and 1·35 francs per kilo from Lyons. These agreements were renewed from time to time up to the end of the war, but during the latter part of 1918 projects were on foot for freeing Great Britain from dependence upon French sources of supply, since the Calais factory was subject to continual attacks from aircraft. By means of this factory at Calais the British had, however, been able to obtain earlier and larger supplies of C.G. than they could otherwise have done, while the supplies of British chlorine enabled the French armies to extend their gas operations. The subsequent efficiency of the Calais factory fully made up for the early delay and by the autumn of 1916 all arrears of White Star cylinders had been made up.

Proposals which were made by the Electro-Bleach Company at the end of March, 1916, to put down a C.G. plant for an output of 14 tons per week were accepted; but the output from this plant was always unsatisfactory, and on 15 August, 1918, control both of this plant and of that erected for the liquefaction of chlorine was taken by the Government.[1]

During the year 1916 arrangements were entered into with Messrs. Ardol, Ltd., Selby, to utilise for the manufacture of C.G. a considerable supply of pure carbon monoxide which the firm expected to produce as a bye-product from their fat-hardening plant. The Company agreed to erect and operate on a separate site plant for an output of about 15 tons of C.G. per week, but as they were unable to complete their fat-hardening plant there were insufficient supplies of carbon monoxide and the output aimed at was never reached. A shell-filling plant for 500,000 3-in. Russian shell was installed at this factory. There shell were filled with C.B.R. mixture, such supplies of C.G. as the Company were unable to turn out being supplied to them from other sources. Subsequently, in the early autumn of 1917, Messrs. Ardol's C.G. factory was taken over by the Government under the Defence of the Realm Act in view of the unsatisfactory output, and eventually the plant was transferred elsewhere.

In March, 1917, though the total estimated capacity of the three plants provided in England was 35 tons per week, the average weekly output was only about 50 per cent. of the capacity, but supplies from France were more regular and reliance could be placed on an average production of 50 tons per week.

At a conference on gas supplies, held by the Minister on 20 March, 1917, it was urged that the capacity for C.G. in this country should be brought up to 100 tons per week, so that in the event of France requiring all her own production Great Britain might be self-supporting. For this purpose decision was taken to erect plant for an additional 70 tons of C.G. per week. A contract was entered into with the United Alkali Company for a C.G. plant for 20 tons per week to be erected at Widnes on the same lines as their (10-ton) Gateshead plant, the process of which they had now completely mastered. This scheme also included the necessary C.B.R. mixing and charging plants, and the works began output in April, 1918.

[1] See above, p. 30.

The final contracts for the supply of C.G. from both the Gateshead and Widnes plants were only signed on 13 November, 1918. The plants had been erected on the Company's land at the cost of the Ministry, whose property they were; but the Company was responsible for repair and maintenance and for operating the plants. The agreed price was 7*d.* per lb. This agreement was to take effect from 1 July, 1918.

Various schemes were considered with regard to the provision of the remaining 50 tons per week of C.G. and several firms were approached. As it was considered advisable to make it from pure carbon monoxide, plans were obtained of the C.G. plant of the Accumulateur Alcalin Compagnie, who used a process almost identical with that of the Usine de Laire. Before this stage was reached, however, there had been some hesitation as to whether or not to carry through the increase of plant in England, as on the one hand there had been some reductions in War Office demands, and on the other, the French authorities had offered an increased supply on favourable terms. Following the revision of the filling programme at the end of November, 1917, financial sanction was obtained for the erection at a contractor's works of a new C.G. plant on the lines of the French process, but it was later considered that there was sufficient capacity in England and France to cover the reduced requirements of C.G. and this undertaking to provide additional C.G. plant in England was abandoned, though, in view of the military conditions at Calais at the time of the Armistice there was a fresh scheme afoot to erect a national phosgene factory at Avonmouth for a production of 225 tons per week beginning in January, 1919. The home production was then at about 25 tons per week and the Usine de Laire, Calais, was producing about 60 tons weekly, for which the price paid was 0·60 franc per kilo in addition to the 90 tons chlorine sent in exchange—*i.e.*, the price of the French C.G. worked out at about 6·7*d.* per lb.

The output of phosgene in Great Britain advanced steadily from 131 tons produced in 1916 to 670 tons, the total quantity made in 1918. The whole amount obtained from France during the war was 6,137 tons, while the aggregate supplies from France and England amounted to 7,499 tons. To these were added during the latter months of the war certain quantities purchased from America at 16 cents per lb.[1]

VI. Arsenious Chloride (B.R.).

A suggestion came from Australia in June, 1915, to employ in chemical warfare arsenious chloride, which had been used in that country for getting rid of prickly-pear cactus growth. About 200 tons was ordered to be shipped from Melbourne at £65 per ton f.o.b. The first consignments were received in the autumn of 1915, and owing to the condition in which they arrived, it was decided to filter the arsenious chloride through anhydrous calcium chloride. This work was undertaken by Messrs. Boake Roberts. No definite use for the

[1] D.E.S./2/56.

material had at that time been decided on, but its condition necessitated its being dealt with at once. In the summer of 1916, when the demand for the C.B.R. shell-filling mixture came forward, it was realised that additional supplies of arsenious chloride would be required, and a quotation for further supplies, under specification, was obtained from the Melbourne firm; but the price named was so high that it was decided to investigate the possibilities of manufacturing in this country. Eventually the United Alkali Company agreed to set up plant for the production of 10 to 15 tons of B.R. per week at Widnes. Considerable initial difficulties were overcome, and eventually, in the summer of 1917, pure arsenious chloride was produced at the rate of approximately 14 tons per week. The firm used their own arsenic recovered from arsenical vitrol and also purchased supplies of white arsenic from home and foreign markets. In August, when further quantities of B.R. were required, the firm put down another type of B.R. plant at Gateshead, which was worked without difficulty from the outset.

VII. Prussic Acid Mixtures (J.L., J.B.R. and V.N.).

At the beginning of 1916, a factory for the production of jellite (J.L.), was in the course of construction at Stratford. The construction, maintenance and output of this factory were controlled by a detachment of the Royal Naval Volunteer Reserve, jellite having been devised by a special committee of the Admiralty set up by the First Lord, Mr. Winston Churchill, in April, 1915. When definite authority was given in July, 1916, to use prussic acid mixtures as shell fillings for the Western front, 50 tons of J.L. were available from the Stratford factory.[1] From about October, 1916, onwards the factory's output was mixed with B.R. to give J.B.R., pending the conversion of the plant to V.N. manufacture.[2] It was decided, meantime, to provide for the production of 20 tons of V.N. per week. For this purpose it was arranged that the constituent materials, *viz.*, sodium cyanide, chloroform, arsenious chloride, and stannic chloride, required for the production of V.N. should be supplied by the Ministry, since the bulk of the output would be required for the army. The Admiralty undertook the charging of shell with J.B.R. and the conversion of the J.L. plant to a V.N. plant producing about 20 tons per week, retaining control of the Stratford factory, which was also utilised for various naval experiments.

Since 1 ton of sodium cyanide was required for each ton of V.N. produced, the supply of sodium cyanide was a matter demanding serious consideration. The sole manufacturers of sodium cyanide in this country were the Cassel Cyanide Company of Glasgow, who had a working arrangement with the Castner Kellner Company, of Newcastle, for the supply of the necessary quantities of metallic sodium. They had realised at the beginning of the war that exports of sodium cyanide from other countries and particularly from Germany would be greatly decreased if not altogether stopped, and they had accordingly decided to increase their plant by about 50 per cent. in order to safeguard the supplies of cyanide required by mines supplying

[1] HIST. REC./R./1650/34. [2] See above, p. 6.

the British Empire with gold and silver. The quantity of sodium cyanide available was limited by the amount which could be obtained from the Cassel Cyanide Company without interference with the necessary supplies to the mines. On 25 February, 1916, soon after the first demand from France for J.L., the consent of the Lords of the Treasury to the use of 17½ tons weekly for military purposes had been obtained, and with a view to the consideration of the question as a whole, the Lords of the Treasury concurred on 10 November, in the appointment of a small informal Cyanide Committee,[1] consisting of a representative of the Bank of England, a representative of the Colonial Office, and the Director-General of Trench Warfare Supplies (Chairman). The first two meetings were held on 5 January and 21 March, 1917, and at the latter it was considered that owing to the arrangements already made the necessary supplies of sodium cyanide for the purposes of V.N. would not in any way interfere with the supplies to the gold mines. These arrangements were as follows: The Cassel Cyanide Company were extending their existing sodium cyanide plant, while a contract for a new metallic sodium plant for 20 tons per week had been entered into with the Castner Kellner Company, at Runcorn, the necessary electric power required for this plant being included in the contract which was then being made with this Company for additional supplies of chlorine. Arrangements had also been made to collect certain quantities of sodium ferro-cyanide and cyanide liquors from gas-works for conversion by the British Cyanide Company, Birmingham, into sodium cyanide. As a result of these arrangements 20 tons a week of sodium cyanide would be provided pending the completion of the new metallic sodium plant at Runcorn. Export of sodium prussiates was prohibited and sodium and potassium cyanides were placed on the "A" list so that they could only be exported under licence, these licences being sent by the War Trade Department to the Chemical Supply Section for endorsement. Thus the Chemical Supply Section virtually controlled the British output of cyanide and this they continued to do with the approval of the Cyanide Committee even after the autumn of 1917, when cyanide ceased to be required for offensive purposes. The third and last meeting of the Cyanide Committee at which this approval was signified was held on 18 February, 1918.

Since it appeared probable that the Admiralty would require the Stratford plant for their own purposes, though they were willing in the meantime that all supplies of V.N. should be used by the army, it was decided to safeguard the future army supplies by the erection of another plant. A contract was accordingly made with the Gas Light and Coke Company, Beckton, for a plant of 20 tons per week capacity, together with the necessary shell-charging plant. As the converted Stratford plant was expected to be ultimately capable of an output of 40 tons V.N. per week, provision had thus been made for a total V.N. capacity of 60 tons per week.

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[1] Hist. Rec./H./1650/4, p. 20.

Certain quantities of shell were charged and sent out to France, but consequent on the abandonment in December, 1917, of V.N. as a service filling, production at Stratford was stopped, as was also work on the new plants, the contracts for which were cancelled. The French, however, continued to use V.N. and about 300 tons of sodium cyanide were sold to them for this purpose.

VIII. Chloropicrin (P.S.), Stannic Chloride (K.J.), and the Mixture N.C.

In January, 1916, a contract was made with Mr. Ellison, of Cleckheaton, a manufacturer of picric acid, for an experimental plant to produce about 1 ton of P.S. weekly, and during February and March, 1916, the manufacture of P.S. was accomplished. Following on experiments with it at Porton on 12 April, 1916, the Chemical Supply Section was recommended to contract for an output of 40 tons per week. Accordingly negotiations were entered into with Mr. Ellison, with the Sneyd Collieries, and the Castner Kellner Company.

The Sneyd Collieries formed a subsidiary company for the purpose called the Sneyd Bycars Company, Ltd., and instructions were given to this Company on 24 May, 1916, to proceed at once with the provision of a plant at Burslem for an output of 20 tons per week of P.S. In four weeks' time P.S. was actually produced. Considerable difficulty was experienced in fixing the price for this novel substance, but the firm continued production pending lengthy negotiations. A contract was signed on 6 July, 1916, the Ministry undertaking to provide picric acid and bleaching powder as free issues, but its terms eventually proved to be unduly favourable to the Company, who offered to forego some of the profit arising therefrom, and a formal agreement was ultimately entered into on 28 February, 1918, which covered the period of production from the beginning of June, 1916, to the end of November, 1917.

Throughout all this period of negotiation the Company continued to carry on production, making many extensions to plant and also designing a mixing plant for N.C. when this filling was substituted for P.S., the requisite K.J. for mixing with the P.S. being sent to them from the Castner Kellner Company.

They attained a rapid and large production, and in March, 1918, when large numbers of 6-in. shell filled with N.C. were required, the production from the plant reached 76 tons in one week, and this pressure was maintained until the signing of the Armistice. Following on the transfer of responsibility for chemical supplies to the Explosives Supply Department in April, 1918, negotiations for a new agreement were based upon the abandonment of the free issue of bleach and picric acid.

Instructions similar to those given to the Sneyd Bycars Company were given to Mr. Ellison, who formed a small company called the West Riding Chemical Company. This Company secured the lease of a disused soap-works near Wakefield and were prompt in getting the necessary plant erected. Output began about two weeks later

than that of Sneyd Bycars. Three agreements were made with this Company: one to cover supplies from the commencement to 30 June, 1917, another to cover supplies to the end of December, 1917, and a third for 1918 supplies.

The highest production from this plant in any one week was 96 tons, or considerably more than the nominal capacity of the plant, which was estimated at 60 tons per week. The Company also designed and provided a very satisfactory shell-charging plant and an N.C. mixing plant, the K.J. for mixing with P.S. being supplied to them by the Castner Kellner Company.

The capacity of the Castner Kellner K.J. (stannic chloride) plant was originally about 30 tons a week, but sufficient fresh plant was bought to double the output. The whole cost of the plant, amounting to about £1,250, was borne by the Government, whose property it was. Free issues of tin spheres were supplied to the Castner Kellner Company, who provided the necessary chlorine and converted them into K.J. at a price of 2*d*. per lb. of K.J., inclusive of all charges.[1]

Pending the provision of plants by the Sneyd Bycars and West Riding Chemical Companies, an offer of Messrs. Castner Kellner was accepted to convert their indigo plant at Runcorn to manufacture 10 tons of P.S. a week. The plant was ready to produce about 2 tons a week early in June, and temporary arrangements were also made for shell-charging.

Some difficulty was experienced in settling terms as to indemnification against explosives risks, and when the Burslem and Wakefield plants began output, all P.S. production at Runcorn ceased and the plant was dismantled.

Early in 1918 a semi-manufacturing plant was put down at Wakefield to test a new process for the manufacture of P.S., but the existing process of manufacture was not altered. In the last months of the war, the purchase of chemical substances from the United States included 400 tons of P.S. at 60 cents per lb., and 500 tons at 50 cents per lb.[2]

IX. Mustard Gas (H.S.).

After the first use of mustard gas by the Germans in July, 1917, an investigation into the production of this new offensive agent was commenced. A process was evolved at the University of St. Andrew's for the production of H.S. from glycol chlorhydrin, which was known as the thiodiglycol (T.G.), thionyl chloride (T.C.) method. By this process H. (dichlorethyl sulphide), which was known as H.S. when diluted with a solvent such as carbon tetrachloride, was prepared by the action of thionyl chloride on thiodiglycol.

The thiodiglycol was obtained by the action of sodium sulphide upon glycol chlorhydrin, which was produced by the union of hypochlorous acid and ethylene.

[1] D.E.S./C.W /235. [2] D.E.S.56.

When the demand for H.S. arose in August, 1917, it was decided to make arrangements for the provision of 15 tons a week. There was in existence a small commercial plant for the manufacture of glycol chlorhydrin at the works of Messrs. Thomas Kerfoot & Company, and though their accommodation was too limited for them to undertake the manufacture of this thiodiglycol except in small quantities, they placed their experience at the disposal of Messrs. Boake Roberts, of Stratford, and Messrs. Henry Ellison, of Cleckheaton, who undertook this work. The estimated total ultimate expenditure on each of the T.G. plants finally erected by these two contractors was £50,000, that of the West Riding Chemical Company being converted later for the production of T.A.[1] The sodium sulphide needed for the reaction was provided by the United Alkali Company. As ethylene had not previously been prepared in this country on a large scale, a process for the manufacture of the gas by passing alcohol through phosphoric acid was worked out and a small plant erected. Since the United Alkali Company already had a small experimental plant which could produce about 200 lb. per week of thionyl chloride (T.C.) they agreed to supply from 5 to 7 tons per week. The estimated total ultimate expenditure on the T.C. plant which this firm finally erected was £100,000.[2] It was provisionally arranged to put down the reaction and solvent mixing plant at an isolated site belonging to Messrs. Henry Ellison, at Mirfield, Yorkshire. As a simpler method of manufacturing H.S. was desired, research was also conducted on the Guthrie process, which involved the combination of ethylene with sulphur dichloride, but it was not then considered practicable.

In the middle of September, 1917, advance notice was received of a largely increased demand for H.S., *i.e.*, about 200 tons per week, and plans were accordingly made for largely increasing output by the T.G.—T.C. process, though at the same time further research was made to find a simpler and more direct process. It was estimated on 15 October, 1917, that the approximate cost would not exceed £4,000,000 and the time occupied would be from 12 to 15 months, output commencing in March, 1918, at the rate of 10 tons per week. This estimate included the construction of a charging, filling, and assembling station. Definite Ministerial authority for the programme was obtained on 5 November, 1917. Meantime, negotiations had proceeded with contractors, of whom a meeting was called on 8 November. The Lords of the Treasury were, however, reluctant to sanction a scheme involving such heavy expenditure in view of the previous outlay on existing poison gas plant and the need for national economy. On 27 November the Minister held a conference on the whole position, and in view of the large capital outlay involved and the length of time required for the whole project, it was ultimately decided to press on with only one-third of the scheme on a high priority and to give lower priority to the remaining two-thirds. The programme of chemical fillings was changed in accordance with this decision in the following December.

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[1] X./C.W./709. See below p. 53.
[2] X./C.W./709.

The requirements, based on the new manufacturing programme, worked out at 60 tons of H.S. per week and entailed a complete revision of the arrangements for contracts which had already been entered into, reducing the estimated capital expenditure from approximately £4,000,000 to £1,300,000.

Meanwhile, a great amount of work had been done by proposed contractors, but on the revision of the requirement in December the whole matter had to be rearranged. To Messrs. Nobel's had been entrusted the provision of the reaction, charging, filling, and assembling plant on a site near Chittening. After considerable discussion as to the desirability of economising by using spare assembling capacity at the National Filling Factory, Banbury, Messrs. Nobel's were instructed to proceed with the reduced scheme on 21 February, 1918. Other work on the T.G. and T.C. process was proceeding satisfactorily, and it was hoped that production by this process would be reached by May, 1918, but before this was attained the T.G.—T.C. process was superseded by the sulphur chloride process.

The adoption of the sulphur chloride process followed on research work done both at Cambridge and Manchester University. As a result of this work the supply department arranged on 24 January, 1918, that Messrs. Castner Kellner should carry out on a semi-manufacturing scale a trial of the new process of preparing dichlorethyl sulphide by passing ethylene into pure sulphur dichloride in the presence of charcoal. Before, however, this arrangement was carried out, a new and better method for the production of H. by passing ethylene into sulphur monochloride was suggested, and on 24 February Messrs. Castner Kellner were requested to work on these lines, the former instructions being cancelled. By this process and with extemporised plant, including rotary absorbers, the Castner Kellner Company eventually produced about 5 tons of H.S., which was despatched to Chittening in July in sealed drums to be charged into shell. Experimental plant was erected on the premises of Messrs. Chance & Hunt under the direction of Sir Richard Threlfall and investigations and manufacturing experiments were carried out there.

To meet the extended programme for chemical production formulated in April, 1918,[1] projects were made for the manufacture of at least 200 tons of H.S. weekly. The scheme of production was again completely revised. It was decided to cut down the T.G.—T.C. process to produce 10 to 12 tons per week, and to provide plant for a 200-ton production weekly by the sulphur monochloride process at Chittening, using Castner Kellner rotary absorbers. This rearrangement again considerably altered the terms of the agreement with Messrs. Nobel's.

Upon the transfer of responsibility for chemical supplies to the Factories Branch of the Explosives Supply Department at the end of April, 1918,[2] the whole position in regard to H.S. supply was reviewed.

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[1] See above, p. 11.
[2] See above, p. 23.

It appeared that[1] the T.G.—T.C. process involved an excessive use of chlorine, was costly and difficult to work, and did not admit of rapid plant erection, though a point in its favour was that only in the last stage in production was a toxic substance formed. The action of sulphur dichloride on ethylene did not give a good yield of H., nor did it give H. in a form in which it could be readily separated from other and inoffensive products which were formed simultaneously in large proportions. There remained the method of preparing H. by the action of sulphur monochloride upon ethylene, and this method had been put into semi-large scale operation by Messrs. Castner Kellner & Company.

Since the T.G.—T.C. method could not be expected to produce within a reasonable time a quantity of H.S. sufficient to justify continuing the erection of the plant in hand, all work was stopped on 8 June, 1918. The Castner Kellner plant was purely experimental and could not be depended upon to produce a quantity of H.S. sufficiently large to play any important role in supplying requirements. It was accordingly arranged to hurry forward manufacture of H.S. on a little experimental plant constructed by the Explosives Supply Department at Avonmouth and to lay out and construct without delay a large-scale plant there for the production of H.S. by the ethylene-sulphur monochloride process at the rate of 400 tons per week.

Messrs. Nobel's willingly withdrew from the proposed Chittening contract, and it was decided that work there should be confined to the charging, filling, and assembling of H.S. shell, for which the Controller of Gun Ammunition Filling had become responsible, while the bulk production of H.S. should be carried through at the H.M. Factory, Avonmouth, which was about 1½ miles from Chittening. This factory had been erected as a picric acid factory, but the discontinuance of the use of picric acid on a large scale rendered it unnecessary to use the plant there for this purpose. Meanwhile, a contract for a subsidiary supply was entered into with Messrs. Levinstein, who had worked out a modification of the ethylene sulphur-monochloride process.

The estimated total ultimate expenditure on the construction of this plant was £25,000.[2] It commenced production in July, 1918, and produced 88 tons in all.

The H.S. plant finally planned for Avonmouth was of a 500 ton per week capacity, the estimated total ultimate expenditure on conversion and construction of plant being £200,000.[3] Some of the plant for ethylene production was brought from other works,[4] and in order to get the earliest possible production, work was started up with makeshift plant. Production began on 3 July, 1918, and on 12 September the final plant was started up, the daily production being 5 tons.

The greatest weekly output reached before the Armistice was 125 tons,[5] and the total output by the end of November was 417 tons.

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[1] HIST. REC./R./1340/39 and 40. [2] X./C.W./709. [3] *Ibid.*
[4] M.C. 1053. [5] HIST. REC./H./1122/28.

The initial difficulties of operation proved very serious. Upon two occasions the entire factory was closed down, and upon one of these the entire technical staff was incapacitated, partly owing to climatic conditions, partly to defects in ventilation.

Sulphur chloride for H.S. production was supplied by the United Alkali Company, who erected two plants at an estimated total expenditure of £10,000, part of their T.C. plant being utilised for the purpose. The price fixed for their sulphur monochloride was £30 per ton. Purchases were also made from Messrs. Castner Kellner at £27 per ton, and these were supplemented by further purchases in America.

A carbon tetrachloride plant was erected at the cost of about £100,000 as a State factory at Langley.[1] It commenced production on 2 September, 1918, and pending its completion carbon tetrachloride was supplied by Messrs. Albright & Wilson.

Since H.S. charging was not done at the producing factories, H.S. was sent to the charging factories, Chittening, Banbury, and Hereford[2] from Avonmouth in tank wagons and from Messrs. Levinstein and Castner Kellner in sealed drums.

Shortly before the Armistice a limited supply of H.S. was received on loan from the United States.

X. The Arsenic Compounds (T.D., D.A., and D.M.).

In January, 1918, Messrs. Boots were asked by the Chemical Warfare Committee to make 10 kilos of triphenyl arsenic dichloride (T.D.) by a process of which details were given them, and later this order was increased. The firm was requested in February to erect a plant on a semi-manufacturing scale to produce about 1 cwt. per week. On 5 March, responsibility for the production of T.D. was handed over to the Chemical Supply Section, and in March, Ministerial authority was obtained to provide plant for the manufacture of T.D., and on 18 March a satisfactory trial run took place at the works of Messrs. Boots, who had modified the proposed process in the course of their investigations. Since they were not prepared to undertake large-scale production, instructions were given on 4 April to the South Metropolitan Gas Company and the West Riding Chemical Company, who had plant that could be modified for the purpose, to provide for a production of 10 tons a week each, and later Messrs. Graesser & Company, Ruabon, were similarly instructed. At the same time investigations were made as to the suitability of spare plant at H.M. Factory, Sutton Oak, for the purpose.

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[1] X./C.W./709.
[2] See below, p. 55.

On 11 April, a demand for a "spot lot" of 50 tons was received and contractors were urged to press on towards an early production. An ultimate output of 40 tons a week was expected and T.D. was placed in the highest position on the table of relative priorities both for labour and materials.

While these arrangements were in progress, the production of diphenyl chlorarsine (D.A.) was under discussion and on 13 May, a demand for D.A. was substituted for that of T.D., 20 to 25 tons per week being requisitioned. By this time the Explosives Supply Department had become responsible for the production of these compounds, and in accordance with their policy of utilising spare capacity at explosive factories, the production of D.A. was carried out at H.M. Phenol Factory, Sutton Oak, which was converted for the purpose at the cost of about £34,500, chemical plant (autoclaves, etc.) being commandeered on account of the urgency of the demand. Output of T.D. commenced on 18 May; but of this compound only about 1½ tons was produced between the date of commencement and 22 June. On 22 June, D.A. was substituted, but bulk production was not reached till November. The total D.A. output was 60 tons, while the total production of the intermediate T.A. (triphenylarsine) was 50 tons. In addition to their own production of T.A., Sutton Oak dealt with T.A. produced at Rainham, for the plant at Rainham, which the South Metropolitan Gas Company had adapted for the production of T.D., turned over to the production of T.A., which was sent to Sutton Oak for final treatment. This plant subsequently became H.M. Factory, Rainham. Its total cost was about £35,000,[1] and it commenced production on 13 June, 1918, producing in all about 18 tons.

The West Riding Chemical Company, who had converted their T.G. plant for the production of T.D. and later of T.A., did not prove very successful makers, nor did Messrs. Graesser, and the work of both these manufacturers was, therefore, terminated.

On 28 June, 1918, the use of D.M. was recommended by the Chemical Warfare Committee, and it appeared probable that about 40 tons a week would be required for use. H.M. Factory, Ellesmere Port, was accordingly converted for the manufacture of D.M. at a cost of about £25,000.[2] Like H.M. Factory, Sutton Oak, it had formerly been a phenol plant and had been put out of commission on account of the reduced picric acid programme. As rapid production was essential, military labour was used both for construction and subsequently for process work. Output commenced in August, 1918, bulk production being reached in December. The total output was 74 tons.

The use of D.A. and D.M. involved the impregnation of absorbent bricks with these substances. These absorbent bricks were prepared by Messrs. Doulton & Company, from Keiselguhr. The impregnation with D.A. was carried out at H.M. Factory, Queen's Ferry, output beginning on 2 November, 1918, and a total of 68 tons being produced.

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[1] X./C.W./709.
[2] *Ibid.*

The impregnation with D.M. was carried out at H.M. Factory, Ellesmere Port, the output commencing in October and the total output being 118 tons. The final filling was done at H.M. Factory, Morecambe, which had been destroyed by fire, but was partly reconstructed for the purpose. Supplies of D.A. and D.M. were just ready for use at the time of the Armistice.

XI. The Completion of Chemical Ammunition.

(a) Charging.

Chemical charging was, as a rule, undertaken by the firm supplying the chemical, as has been indicated throughout, but the firm supplying the lachrymatory substance S.K. was unable to undertake in bulk production the charging of the grenades for which it was first used, and Messrs. Baird & Tatlock, who provided the necessary glass containers, agreed to undertake the charging, filling, and assembling of these at Walthamstow. They accordingly erected the necessary buildings and plant on a cost basis under the supervision of the Trench Warfare architect,[1] and work upon the grenades began about August 1915, experimental substances other than S.K. being at first used.[2]

To the work with grenades was added early in 1916 the charging of shell and bombs with S.K. and P.S., and later, early in 1917, experimental work was done on charging with N.C.[3]

During the early part of the year 1918 the charging of large 6-in. shell with S.K. was the chief work of the Walthamstow factory, 187,000 6-in. shell being charged during the period January to June. The evacuation and disassembling of 4-in. lethal Stokes bombs was also undertaken, the P.S. from them being utilised to fill N.C. Livens drums.

In June, 1916, in consequence of unsatisfactory output, the Walthamstow chemical station was nationalised, an agency contract being entered into with Messrs. Baird & Tatlock,[4] who continued to operate the factory until 1 November, 1917, when the entire control was taken over by the Trench Warfare Supply Department.[5]

The charging of lethal substances other than those produced and charged at the Admiralty factory at Stratford, and at the Usine de Laire, Calais, was undertaken by the trade producers, but for a time Walthamstow undertook to deal with P.S. manufactured at Burslem and Wakefield, though ultimately provision for charging was made at these two factories. In the plants for charging projectiles erected at contractors' works, the method of charging was laid down in principle only and the design and provision of the plant and apparatus was then left largely to the contractors, subject to the approval of the supply officers.

[1] Hist. Rec./H./1600/9.
[2] Hist. Rec./H./1650/4.
[3] Hist. Rec./H./1122.7/13.
[4] Hist. Rec./H./1650/4.
[5] Hist. Rec./H./1122.7/13.

H.M. Factory, Walthamstow, for long remained the only independent charging station for chemical shell, but with the reorganisation of administration which took place in April, 1918, the policy of charging H.S. at a station separated from the producing factories was adopted. It was decided that the final production of H.S. should not be carried out at Chittening as had been originally intended, but at H.M. Factory, Avonmouth, and the Chittening site was accordingly handed over to the Controller of Gun Ammunition Filling for use as a charging, filling, and assembling station only. Subsequently additional accommodation was found for charging, filling, and assembling at the National Filling Factories at Banbury and Hereford,[1] which had previously been occupied in filling H.E. shell.

The estimated outlay on the construction of H.M. Factory, Chittening, was £750,000. The shell finally dealt with there were all 6-in., as it was decided to send the 4·5-in. and 18-pdr. shell to Banbury and Hereford, and to reserve the accommodation at Chittening for shell of larger nature. The H.S. was conveyed to the factory in drums and tank wagons. It began to come forward early in July and output started at Chittening on 8 July, and shortly afterwards at Banbury.

When H.S. manufacture began, labour had become very scarce, and some additional difficulty was experienced in getting suitable labour owing to the unpleasant nature of the work. Owing to the urgency of the demand for H.S. the Minister decided that, if necessary, formal arrangements with regard to labour must be disregarded, and in September a "danger bonus" was accordingly conceded at Banbury to workers engaged on H.S. charging.

A list showing the plant which was provided for charging is given in Appendix VIII.

(*b*) Filling and Assembling.

When a demand arose for 4·5-in. artillery shell containing chemicals, these shell were sent to Walthamstow for charging with S.K. and the subsequent filling and assembling was also undertaken at this factory, distinct buildings being added for the purpose in March, 1916. The filling and assembling of the 4-in. Stokes bombs charged with S.K. and phosphorus, for which a demand arose in the autumn of 1915, was undertaken at the Hammersmith Distillery.

The decision to use lethal substances in artillery shell and Stokes bombs necessitated special filling and assembling arrangements as it was undesirable to introduce explosives into chemical manufacturers' works where it was intended to charge lethal substances produced direct into shell. A proposal was made to erect a new filling and assembling station entirely for chemically charged shell, but it was decided in June, 1916, that the filling and assembling of the charged lethal shell should be done at the Ordnance Factory, Woolwich.

[1] Hist. Rec./R./1340/42

After two months' experience, however, it was found that the work really needed specially isolated buildings, and the erection of a separate filling and assembling station for both lachrymatory and lethal shell was decided upon (August, 1916). H.M. Factory, Greenford, was accordingly erected, but pending its completion Walthamstow continued filling and assembling lachrymatory shell, and Woolwich lethal shell, and even after Greenford came into commission in January, 1917, the Ordnance Factory continued to deal with the filling and assembling of smoke shell.

Spare capacity was also made use of at two of the Trench Warfare National Filling Factories—these were Watford No. 1 and Watford No. 2. At the former the filling and assembling of chemical bombs was undertaken in July, 1916, and early in 1917, when there was an urgent demand for chemical bombs, the station was engaged exclusively on this work.[1] At Watford No. 2 chemical shell were dealt with at a time when additional capacity was needed. Owing to the increase in the gas programme it was decided on 22 March, 1917, to double the capacity of Greenford and the erection of a second national station for chemical shell filling and assembling was even contemplated. To avoid this, work with chemical shell was undertaken at Watford No. 2 and during the early summer of 1917 the factory concentrated on the work. With the completion of the Greenford extensions the work ceased.

Special arrangements had to be made for the filling and assembling of the Livens drums charged with C.G. at Calais. Exploder charges were sent out packed in tin cases, and despatched with the charged drums from Calais to the store depôt of the Special Brigade for filling and assembling.

In January, 1918, it became necessary to provide additional filling and assembling capacity to meet the increased requirements for chemical projectiles, and as it was not possible further to extend the Greenford factory, owing to the lack of railway sidings, it was proposed to provide accommodation for filling and assembling at the site at Chittening which had been selected for the H.S. final reaction plant and charging station. H.M. Factory, Chittening, ultimately became a charging and filling station only, the large shell dealt with there being assembled on the field, but at the national filling stations of Banbury and Hereford, H.S. shell were not only charged and filled, but also assembled, while H.S. shell that could not be assembled concurrently with charging and filling at Banbury and Hereford were sent on to the National Filling Factory at Hayes, where there was spare accommodation for assembling. The total output at Chittening in shell charged and filled with H.S. was 85,424 6-in. shell. Beginning in July, Banbury completed over 82,000 4·5-in. shell and 20,000 18-pdr. and forwarded over 200,000 18-pdr. to Hayes, while Hereford, beginning in October, completed over 3,000 4·5-in. shell and forwarded about 1,000 18-pdr.

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[1] Hist. Rec./H./1600/9.

to Hayes. Work at Hayes was begun in the week ending 23 August, 1918, and the total number assembled was just over 200,000 18-pdr.[1] All these were H.S. shell, but head filling of some 6-in. shell charged with N.C. and C.G. had previously been undertaken at Banbury at the end of May, 1918, and also at Hereford.[2]

A list of factories used for the filling and assembling of chemical projectiles is given in Appendix IX.

In connection with cylinder charging a cylinder depôt was instituted at Bucknall Saw Mills. From 1 July, 1917, this became a national factory, as it was found impossible to ensure efficiency and economy by other means. Here returned cylinders from the front were received, residues of gas evacuated, and the cylinders cleaned, tested, repaired, and re-valved.

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[1] C.R./Filling/316.
[2] HIST. REC./R./1340/39.

CHAPTER V.

MEDICAL RESEARCH: PREVENTION AND CURE.

Rapid developments in making and handling toxic substances gave rise to grave difficulties in regard to the prevention and cure of industrial disease. In order to solve these problems, investigations which would normally have occupied a lifetime of patient study were concentrated into a few months. The comparison of the data obtained from the factories increased vastly the scanty existing information touching the physiological effects of various substances. In more than one instance, medical officers attached to the factories or laboratories where poison gas was produced subjected themselves to its effect in order to augment their knowledge. It was necessary to increase, and if possible to forestall, experience in the field, and to supplement the researches of the anti-gas authorities from every available source of information. Moreover, in the interests of humanity as well as of output, the Department was deeply concerned in the health of the workers who came into contact with lethal substances. The prevention of casualties in the workshops stood second only to the prevention of casualties in the field, *i.e.*, manufacture was continued under unsatisfactory conditions only when immediate output was considered of primary importance to the success and *morale* of the army. The measures adopted for the general welfare of poison gas workers have been narrated elsewhere.[1] It remains to describe how the difficulty of this problem grew with the increased use of chemicals in warfare and what preventive and curative steps were taken with the advance of knowledge and the adoption of new substances.

I. Early Arrangements, 1915–1916.

During the first year of chemical warfare, *i.e.*, from May, 1915, until the following spring, the chemical chiefly produced for military purposes was liquid chlorine. Manufacture was carried out in the works of firms already experienced in the production of alkalies and under the conditions already laid down by the Factory Acts. Chlorine had for some years been included among the industrial poisons, whose effects were studied by H.M. Medical Inspector of Factories. Preventive measures in the chlorine factories were comparatively easy, as immunity from disease might be practically secured by the wearing of a suitable respirator or other simple precautions. The manufacture of phosphorus for smoke production remained also with the old-established makers, who were bound to notify any cases of poisoning arising from work in their factories.[2] Even with the novel production of mustard gas in 1918, it continued to be a remarkable fact that industrial disease was less prevalent in the works of old-established chemical manufacturers than in the new factories built solely for the purpose of the war.

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[1] Vol. V, Part III, pp. 79–82.

[2] *Annual Report of the Chief Inspector of Factories and Workshops*, 1914, pp. 81–84.

The measures taken by contractors to prevent disease and to provide for compensation varied very considerably. Compensation was, in fact, legally due in case of accident only, and not in respect of the incapacitation which arose from the slow inhalation of poison gases such as chlorine, S.K., or P.S. The Workmen's Compensation Act of 1906 provided for cases of disablement arising from certain scheduled diseases only, such as arsenic, phosphorus, and lead poisoning, which were the well-known results of existing commercial undertakings. Every poison gas factory had, however, some scheme for compensating workpeople during illness, but the basis of the schemes differed slightly and they did not always provide for adequate study of the diseases peculiar to individual processes. Thus, as late as July, 1917, no exhaustive information as to the amount of sickness among the employees engaged in the manufacture of S.K. was available, since the factory where it was made had no recognised medical officer, and the contributors to a medical fund there formed only a small proportion of all the operatives.

At the factories which were hurriedly improvised for charging lachrymators into grenades during the summer of 1915, scarcely any precautions were taken to protect the workers, mostly volunteers, from the discomforts of the process. "For this work there were no specially planned factories with strong currents of air sucking the fumes away from the workers, no scientifically designed respirators, and no doctors or nurses who had the slightest idea how to treat casualties ; . . . these workers . . . inspired by the patriotic fervour of the early days of the war, and with no other protection than roughly made pads tied over their noses and mouths, ordinary motor goggles and rubber gloves (which were of little use) cheerfully faced each day an atmosphere impregnated with . . . sulphurous gases, the potency of which was enhanced by admixture with . . . cayenne pepper."[1]

II. Methods of Dealing with Lethal Substances, 1916–1918.

To have applied such methods to the manufacture and charging of the highly lethal substances which were produced from 1916 onwards would have been to court disaster. In July, 1916, at the instance of the Physiology Committee of the Royal Society,[2] the Trench Warfare Supply Department appointed a special medical adviser, Dr. F. Shufflebotham, who had long made a particular study of industrial diseases. During the following half-year he investigated the effects of dangerous processes in poison-gas manufacture upon the human subject, and somewhat later he reported on hygienic conditions in the chemical factories. In February, 1917, he became responsible for administering and supervising all medical and health conditions at the factories where chemicals were made and charged, as well as at those filling factories where trench warfare projectiles were loaded with

[1] Hist. Rec./R./1650/1.
[2] See above, p. 20.

explosives. He immediately proceeded to organise the medical services at the different factories. Medical officers were appointed to each factory, and were in the direct employment of the Welfare and Health Department. Their duties were defined in April, 1917. They were to attend regularly at the factories in order to examine applicants for work and to make a fortnightly examination of all employees, keeping a register of results. They were to examine and treat employees with regard to "illnesses arising out of the employment," and those who had sustained minor injuries, but were able to continue work. They were to answer emergency calls, to keep a complete record of accidents and illnesses arising out of the employment, notifying the Medical Adviser of new aspects of gas poisoning. They were to send serious cases to the local hospitals, to make special reports on workmen suffering from accident or illness arising out of their employment, to be responsible for the efficiency of ambulance stations which were established at each factory, and to report regularly to the Medical Adviser. About the same time (24 April, 1917), contractors and managers were informed that it would thenceforward be compulsory to notify the occurrence of all accidents and illnesses arising out of the employment, and to keep a record of them. They were to notify all such cases of poisoning, inflammation of the eyes due to irritating fumes or other causes, eczematous ulceration of the skin arising from the handling of material, gassing, and injuries through mechanical accidents. These last were apt to have extraordinarily serious results on account of the toxic qualities of the substances which the workers were making or handling. From time to time the Medical Adviser issued regulations to the factories and provided the medical officers with information as to the precautions to be taken against the effects of new substances and as to methods of treatment. The work of the visiting doctor of each factory was supplemented by that of permanent nurses.

These arrangements had a twofold result. On the one hand, they provided the operatives who came in contact with poison gas at any of the factories with comprehensive means of obtaining medical advice, and the Department with a check on claims made in case of disease or accident. On the other, they kept the Medical Adviser at headquarters informed as to all the data which could possibly be obtained as to the physiological effects of the different mixtures and the results of various methods of treatment.

III. Preventive Measures.

Numerous precautions were taken to lessen the dangers incident to poison gas manufacture. During the latter part of the war the class of employees engaged was watched very carefully, since it was realised that certain types of workers were peculiarly disposed to gas poisoning. The enlistment of young and healthy men had restricted the recruits for the manufacture of chemicals to men who were suffering from organic disease or disability or were over military

age. The work at the filling stations, such as Walthamstow, was mostly discharged by women. From the date of their first appointment the medical officers rejected applicants who were predisposed to gas poisoning by certain organic diseases, *e.g.*, chronic lung disease, heart disease, or digestive troubles. Steps were also taken to eliminate gradually any persons who had already undertaken work for which they were unsuited.[1] In August, 1918, however, the general shortage of labour was so great and the demand for chemical workers had so increased that the medical examination of new employees was suspended and applicants were no longer prevented from beginning work on medical grounds.

The construction and management of the factories were gradually suited to the work undertaken in the face of enormous difficulties arising from inexperience, the need for haste, and the general shortage of skilled labour. In particular, the shortage of skilled fitters led to many defects in joints and valves. In all factories a strong system of ventilation was introduced to draw fumes away from the workers' benches, and in some there was a double system in case of breakdown. Charging cabinets of various types were installed as the result of experience with new mixtures. Thus, at Gateshead, a considerable proportion of casualties among workers engaged in charging with C.G. was greatly reduced by the introduction of a charging cabinet and the shutting off of the C.G. tanks from the charging shops. Great stress was laid upon the provision of adequate washing accommodation; washing before meals and before leaving the factory was made compulsory. Some firms erected bathrooms for their workers, since it was realised that the general cleanliness of the skin aided in the prevention of poisoning. Working hours were also closely regulated. Thus, the women engaged at the Middlewich factory had a clear 34 hours off work in every three weeks. As the manufacture of more potent substances developed the need for alternations of labour increased. Thus, for instance, the operatives engaged in H.S. factories needed long periods of rest or frequent changes in the nature of their work.

The personal precautions to be taken by the workers varied very considerably with the nature of the process. A few illustrations will suffice to show their general character. At Runcorn, the workers engaged in making and charging K.J. during the year 1916 took no precautions, since the process was practically a closed one and the irritative cough to which escaping fumes of stannic chloride occasionally gave rise disappeared rapidly when the cause was removed. At Gateshead, considerable trouble arose from eczematous ulceration of the hands among the women who handled shells filled with C.B.R., until in the summer of 1917 the medical officers insisted upon the frequent use of olive oil, whether the workers wore gloves or not. All contractors provided their employees with suitable clothing and were responsible for its washing. During the autumn of 1917, Dr. Shufflebotham made special investigations into the number and nature of the helmets and respirators provided in factories where these were

[1] Annual Report of the Medical Adviser, October, 1917.

needed. Smoke helmets were worn at Burslem during the charging of reaction vessels with picric acid for the manufacture of P.S., and the fresh air was drawn to them from a field at some distance from the plant. In many factories, however, helmets were only needed in case of emergency, such as a serious escape of gas. For this purpose, they were distributed among the emergency gangs or hung upon marked posts in readiness for use. Special protective clothing was supplied to workers in H.S. factories, but they frequently preferred the use of their ordinary overalls, and were to some extent justified by the ease with which the special clothing became contaminated.

The introduction of H.S. brought with it a series of specially grave difficulties which were enhanced by the insidious nature of the substance. The faint odour which denoted the presence of the vapour soon became undistinguishable by the workers. A splash of the colourless liquid on the skin would ultimately cause a serious burn, but no immediate pain was felt. A splash on the clothing, or even on leather boots, would in time have a similar result, while the physiological effects from inhaling the vapour given off when the liquid came into contact with the heat of the body were even more grave. Constant work where the faintest vapour was present seriously lowered the vitality.[1] These difficulties were increased by the nature of the process and the urgency of output which necessitated the use of improvised plant and the working of the factories before sufficient experience of the properties of H.S. could be obtained. Extreme care was used to prevent contamination of the machines, which were washed with specially prepared solution at the end of each eight-hour shift. The rags used for wiping away splashes were washed in similar solutions or destroyed ; and even this had to be done with care, since it was known that the burning of a single rag had incapacitated practically the whole of the staff of a single laboratory. Bleach, or a mixture containing bleach, was constantly used for spills on the floor or to catch drips ; but this method was apt to give rise to false security, since it was difficult to ensure actual contact between the bleach and every portion of the spilt H.S. Buildings and plant were sprayed with chlorine or washed with steam upon occasion. In the end, however, experience showed that safety lay mainly in an extremely high standard of ventilation, and particularly in the employment of a strong exhaust down-draught. In October, 1918, the difficulty of ventilating the Avonmouth H.S. plant was so much increased by climatic conditions that the factory ceased work for a considerable time. Personal precautions included a hot bath daily upon leaving work, frequent washing with liquid soap, as, *e.g.*, before meals or before touching the eyes, face, or ears, and the immediate removal of clothing which had been splashed. It was only by the most minute attention to such details of factory life that there was any hope of preventing chronic poisoning with varying degrees of digestive disorder, nervous trouble, inflammation of the eyes, kidney trouble, and general lowering of the workers' health.[2]

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[1] Report of Conference on H.S., 11 July, 1918 (Hist. Rec./R./1340/39).

[2] Medical Research Committee. *Report on the Medical Aspect of the Production of Mustard Gas.* (January, 1919.)

Owing to the nature of the work on D.A. it was found necessary to employ labour for six-weekly periods with a fortnight's holiday between in order to eliminate the arsenic from the system. It was further arranged that workers engaged in the manufacture of D.A. or D.M. should have six months' full pay if certified sick from gas results.

IV. Medical Treatment and Research.

Minor casualties in poison gas factories were treated at the works ambulance by the nurse in charge and were also treated by the visiting doctor. Since the slightest injury was liable to set up blood-poisoning extraordinary care was necessary in these cases. Special arrangements were made for the treatment of more serious illness or accident in the local hospitals visited by the medical officer to the factory. In one or two instances a factory hospital was installed. Thus, one firm set up a hospital for their employees at Runcorn under the charge of the works doctor, and a hospital was erected at Avonmouth, to serve the H.S. factory and the neighbouring filling factory at Chittening. These methods greatly facilitated the study of the pathological aspect of poisoning; but in October, 1917, the Medical Adviser urged that a scientific investigation should be made into every serious case of gas-poisoning along certain fixed lines and that a post-mortem examination should be invariably carried out in every fatal case.

During the year 1918, a special study was made into the reported immunity of poison gas workers from influenza, comparison being made between the prevalence of the epidemic among operatives at various classes of factories and among the ordinary panel patients of the factory doctors. These researches established the fact that workers engaged upon chlorine processes were relatively immune from infection or, at least, developed a comparatively mild form of the disease. Similar evidence showed that workers where arsenic compounds were manufactured were practically immune to influenza. In one factory, for example, 50 per cent. of the general body of workpeople suffered during a single epidemic, but 3 per cent. only of the arsenic workers were incapacitated on this account. In three other centres where arsenical compounds were made, cases of influenza were comparatively few and not a single case of pneumonia arose. In the H.S. factories also, the normal rate of absenteeism was maintained during a local epidemic of influenza. On the other hand, reports from factories where C.G. was made or charged showed that these workers were more prone to influenza than other classes.[1]

One of the most notable of the therapeutic advances which were made arose from a systematic investigation into the use of oxygen. As a result of experiments originally carried out at the Physiological Laboratory, Cambridge, research was started on a large scale at the North Staffordshire Infirmary, Stoke-on-Trent, under the auspices

[1] Dr. F. Shufflebotham. Report on Influenza among Poison Gas Workers (1919).

of the Medical Research Committee of the Royal Society. Two specially constructed wards were opened in October, 1918, for the treatment of gas-poisoning by the continuous inhalation of oxygen. They were made air-tight by means of special fittings and were divided from a common corridor by means of steel and glass screens. The oxygen was admitted from cylinders on a lower floor and the atmosphere was purified by scrubbers and the temperature regulated by means of steam coils. Although the wards were originally established for the treatment of patients from the poison gas factories, they were eventually used for military cases. The investigations ultimately met with very considerable success, but they were seriously hampered by the high cost of oxygen, manufacture of which was in the hands of a monopolist company.[1]

During the war, the workers who were exposed to the greatest risks were those engaged upon the emptying and cleansing of cylinders at Bucknall Saw Mills, near Stoke-on-Trent. The evasion of peril in such work was a matter of peculiar difficulty, even though investigation was actively prosecuted. The results of escapes of gas were, however, considerably alleviated by the efficiency of the ambulance arrangements. Thus during the year ending October, 1917, 459 escapes of gas affected the workers ; but only nine claims were made for compensation on the ground of incapacity for work.[2] With the close of hostilities this problem grew in intensity as the chemical and filling factories undertook the emptying and dis-assembling of all surplus chemical projectiles. The medical work arising from these processes thus tended to increase enormously after the Armistice. The achievements of this later period lie, however, outside the scope of this narrative.

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[1] *Proceedings of the Royal Society of Medicine*, Vol. XIII, pp. 59–95.
[2] Dr. F. Shufflebotham. Annual Report, 8/10/17.

CHAPTER VI.

DEFENSIVE APPARATUS.

I. Development of Apparatus.

(*a*) Early Forms of Respirators.

When the Germans made their first gas attack on the French forces, on 22 April, 1915, the British troops were entirely unprotected, but within 36 hours an improvised mouth-pad had been issued to every man in the line.[1] Measures were immediately taken to discover a more efficient anti-gas apparatus. Dr. J. S. Haldane, an expert on mining gases, and Professor H.B.Baker were sent by the War Office to France to give advice and obtain information, while the provision of appliances was placed in the hands of the Royal Army Medical Corps. The development of administrative arrangements for the provision of defensive apparatus has already been described.[2] The improvised mouth-pads, which were at first produced mainly by voluntary effort, were rapidly replaced by a standard type of respirator, which was manufactured in large quantities. The first of these to be produced on a manufacturing scale were made on 6 May, 1915, and consisted of a pad of cotton waste impregnated with a solution devised by Professor Baker and wrapped in muslin or veiling, the ends of which could be tied round the back of the head. Large numbers of these respirators were issued in May, June and July, 1915. Other designs of this type included the Phenate Ricinate, the "Hypo" snout, and the "Hypo" horse respirator.[3]

(*b*) Helmets and Goggles.

The idea of the helmet type of protection had, however, been brought to England on 10 May, 1915, by Capt. MacPherson, and on the same day a flannel helmet with a mica window was made at the Millbank Laboratory and withstood all tests. The manufacture of the H. (hypo) or smoke helmet was begun in June. It was made of flannel dipped in saturated thio-sulphate solution, to which sodium carbonate and glycerine were later added. Improvements were introduced; the mica window was replaced by celluloid, sewn into place, and afterwards by celluloid eye-pieces screwed into position; impregnation by dipping and partial drying replaced impregnation by spraying,[4] and flannelette was used instead of flannel, which was found to rot.[5] In July, 1915, the P. (phenate) helmet was introduced

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[1] Hist. Rec./H./1650/10, No. 11.
[2] See above, p. 19.
[3] Hist. Rec./H./1650/12, No. 8; Hist. Rec./H./1650/13, No. 11.
[4] Hist. Rec./H./1650/13, No. 12, p. 2.
[5] *Ibid.*, p. 3.

with a second layer of flannelette, and it was followed by the P.H. (phenate–hexamine) helmet. The hexamine was added on a suggestion from Russia to provide better protection against phosgene. This P.H. helmet or the P.H.G. (phenate–hexamine goggle) helmet was issued from January, 1916, until February, 1918, when the helmet type of protection was given up.

The great objection to the P.H. helmet, besides its discomfort and the difficulty in cleaning the eye-pieces, was the inadequacy of the protection it afforded against lachrymatory gas. This was first used in the autumn of 1915, and separate goggles of various types were issued as a protection. The first type was made of rubber with glass eye-pieces, but it did not fit tightly enough and a pattern of French origin was adopted, made of impervious cloth lined with flannelette and fitted with sewn-in celluloid eye-pieces. A piece of soft iron wire was sewn into the lower edge of the fabric so that it could be fitted to the bridge of the nose. This was effective against low concentrations, but when stronger lachrymators were introduced it was found that rubber sponge was the best protection. The final form consisted of a base of impervious fabric (impregnated with gelatine formalin solution) lined with soft material to which were solutioned and sewn two halves of an oval rubber sponge. Into holes cut out of the sponge and base were fitted glass eye-pieces screwed in metal. The issue of sponge goggles was stopped in 1917, when concentrations of lachrymators, such as benzyl and xylyl bromides were used of such a strength that respiration was affected as well as sight.[1]

(c) BOX RESPIRATORS.

No experiment in the helmet and goggle type of apparatus produced a successful protection against high concentrations of phosgene, lachrymators, and arsine. In consequence, the idea of a box respirator, in which solid absorbents could be placed, gained in favour and was present all through the summer of 1915. The origin of the box respirator is difficult to trace, but one of the most important steps was undoubtedly the discovery of a method of making lime permanganate granules, which would absorb chlorine, phosgene, prussic acid, arsine, etc. Further experiments resulted in the soda–lime–manganate granule, of which the formula was communicated to Messrs. Boots, Ltd., of Nottingham, in December, 1915. This firm began the manufacture of the granule, which came to be known as the "Boots" granule. Further experiments were made as to the shape of the container and composition of the mask and other parts, and the large box respirator (Harrison's Tower) resulted. It was issued during 1916, mainly to gunners, but was ultimately replaced, except for the Special Brigade, Royal Engineers, by the small box respirator, which was less cumbrous and more suited to general use.[2]

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[1] HIST. REC./H./1650/13, No. 12, p. 4.
[2] *Ibid.*, pp. 4, 8.

The small box respirator was first issued in August, 1916, and continued in use, with certain modifications, until the signing of the Armistice. It consisted of a loosely fitting mask, made by pleating a flat piece of proofed material, which was impermeable for considerable periods to all gases, and thus provided protection for the eyes against lachrymators. It was provided with a mouth-piece, nose-clip, and goggles, and fitted tightly across the forehead, down the sides of the cheeks and under the chin, being held in place by elastics and tape. Temple pockets were provided so that the goggles could be wiped by inserting the forefinger into the pocket. The nose-clip ensured that by closing the nose all inspiration and expiration took place through the mouthpiece. The mask was connected with the box by a metal angle tube and a rubber breathing tube. An expiratory valve was fitted to the inner limb of the angle tube, while the inspiratory valve was carried in a push-in lid, which fitted into a hole at the bottom of the box or container. Certain changes were made in the mask and other parts and the celluloid eye-pieces were replaced by splinterless glass, but research as a whole was centred in the contents and packing of the container.

The chief changes made were the substitution of wood charcoal for animal charcoal in the summer of 1917; the evolution of the F. granule and the white granule; variations in the fillings of the box, in order to give the highest degree of protection against different concentrations of various gases (phosgene, chloropicrin, arsine, hydrocyanic acid, cyanogen, etc.).

In the early part of 1917 the use of irritant toxic "smokes" resulted in a further development of the small box respirator. Protection was best obtained by mechanical filtration, by means of a pad of dry cotton-wool, and as the matter was urgent this had not only to be introduced in the containers of new respirators, but had to be fitted to respirators already issued. This was done by the issue of the "extension" box, which could be fitted to the container; besides the pad of cotton-wool, a mixture of white and F. granules was introduced as an additional protection against hydrocyanic acid. The extension box was an emergency measure and steps were at once taken to introduce the increased protection it afforded into the main container. Further experiments produced the N.C.5 or N.C. canister.[1] The chief difficulty in use was the increased resistance to breathing consequent on the introduction of the pads, but this was found to be due partly to the rusting of the wire gauze and was overcome by the substitution of a galvanized non-rusting gauze for ordinary iron wire gauze.[2]

In the first half of 1918, cellulose jackets, which formed porous coverings to the containers and acted as filters, were issued.[3] The whole small box respirator was packed in a waterproof haversack, together with repair and anti-dimming outfits.

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[1] HIST. REC./H./1650/13, No. 5.
[2] *Ibid.*
[3] HIST. REC./H./1650/12, No. 5.

During 1918, it was decided to introduce a new type of container known as the "Green Band" container, and manufacture was started in September. Although large quantities were made, no respirators fitted with this container had been issued to the troops before the Armistice was signed.[1]

(d) PROTECTIVE CLOTHING.

Other anti-gas appliances issued included impregnated leather gloves, chiefly used as a protection against burns produced by handling guns, sandbags, etc., splashed with mustard gas. With these gloves, cotton gloves were also issued, partly to afford a more adequate grip and partly as a protection to the leather gloves, traces of gas being more noticeable than on the oiled leather gloves.

Linen suits, impregnated with prepared linseed oil, were issued for the same purpose as the gloves. They were not used during a gas attack, but by troops in areas in which mustard gas had been employed.

Pigeon basket covers were also issued. The tops and sides were made of flannel or flannelette impregnated in the same way as the "Hypo" helmet and fastened with a drawing at the bottom. The cover was slipped over the basket and both were placed in a fitting canvas bag.[2]

II. Methods of Supply.

(a) INTRODUCTORY.

No special organisation for supply was instituted, when the Royal Army Medical Corps were placed in charge of the provision of anti-gas apparatus. After the first gas attack an emergency committee sat at the War Office to consider the question of defence, and at its meeting on 28 April, 1915, a member of the firm of Messrs. John Bell, Hills & Lucas, chemical manufacturers, appeared as a possible manufacturer of anti-gas apparatus.[3]

The original improvised mouth-pad, however, was made by voluntary women workers and issued within 36 hours of the first gas attack. It was packed by shifts of women, organised by the Women's Emergency Corps.[4]

The first order on a manufacturing scale was given by word of mouth to Messrs. John Bell, Hills & Lucas, when on 6 May, "Colonel French and Colonel Fitzgerald called at Oxford Works and asked for 250,000 of the cotton waste mouth-pads."[5] Word of mouth orders

[1] HIST. REC./H./1650/13, No. 7.
[2] *Ibid.*, No. 11.
[3] HIST. REC./H./1650/12, No. 8, p. 1.
[4] HIST. REC./H./1650/13, No. 11, p. 3.
[5] HIST. REC./H./1650/12, No. 8, p. 1.

were given throughout the first summer, but in July, 1915, the need for greater regularity was recognised and the Anti-Gas Supply Committee was appointed, under the presidency of Colonel (afterwards Sir William) Horrocks, K.C.M.G. This Committee not only consisted of representatives of the branches of the War Office concerned with anti-gas apparatus, but it was regularly attended by members of the firms of Messrs. John Bell, Hills & Lucas, Ltd., and Messrs. James Spicer & Sons, Ltd., whose works formed the nucleus of the large group of London anti-gas factories.[1] The Anti-Gas Supply Committee introduced a regular system, by which all demands received by the Army Ordnance Department for apparatus were considered and orders thereupon placed for the necessary supplies through the Contracts Branch of the War Office. It kept in touch with army requirements, receiving daily reports from G.H.Q. and thus keeping pace with the rapid developments in the enemy's use of toxic substances. It advised the Contracts Section concerned not only as to the quantities of material to be supplied but also as to the best sources of supply.[2]

For two years, the Committee met daily, but in June, 1917, its sittings were reduced to three times a week, although the secretary had still to bring daily reports of progress to the president at Millbank.[3] Its work was considerably decreased during 1917 owing to the decision to establish in the Anti-Gas Department a special section to supervise the supply of component parts to the respirator factories and obtain sufficient supplies of raw materials. When the department was transferred in November, 1917, to the Ministry of Munitions, this supply section had developed so rapidly that there was no further need for the older Supply Committee, which was dissolved. At the same time, the Contracts Branch of the War Office, dealing with anti-gas supplies, was transferred to the Ministry of Munitions, Mr. Osborne of the Contracts Branch and Secretary of the Supply Committee becoming a Section Director and Director of Anti-Gas Contracts.[4] During the whole of its existence, the Committee dealt with the question of supply in its widest sense, being responsible not only for materials and apparatus, but for questions of experimental research, the receipt of complaints and suggestions from chemical advisers in France, and for inspection, labour, and transport.[5]

Until late in 1916, the manufacture of anti-gas apparatus was carried on entirely through contractors, no work being done in a Government factory, except the cutting and sewing of a certain number of helmets at the Royal Army Clothing Department's factory at Pimlico.[6] The apparatus was divided up into as many components as possible in order to make use of special types of machinery. The Committee persuaded manufacturers, who were normally engaged

[1] HIST. REC./H./1650/13, No. 2, pp. 2-3 and Minutes of Anti-Gas Supply Committee.
[2] HIST. REC./R./1660/21.
[3] Minutes of Anti-Gas Supply Committee. (5/6/17.)
[4] HIST. REC./H./1650/13, No. 2, p. 3.
[5] Minutes of Anti-Gas Supply Committee *passim*.
[6] HIST. REC./H./1650/13, No. 11, pp. 6, 7.

in producing large quantities of general commodities such as metal polish, blacking, starch, and bottle capsules, to adapt their machinery for the production of small metal components. The two chief firms to take up this new industry were the Matchless Metal Polish Co., Ltd., of Liverpool, and Robert's Capsule and Stopper Co., Ltd., of London.[1] In February, 1917, a granule factory at Stamford Hill started operations under the direct control of officers of the Anti-Gas Department. While steps were taken during the year 1918 to nationalise work at certain trade factories,[2] no other Government factory was started for anti-gas apparatus until the department passed from the War Office to the Ministry of Munitions. In August, 1918, when the manufacture of the "Green Band" respirator was about to be started, the department secured the Batavia and Holloway Mills at Holloway for this purpose and converted them into national factories with plant of the latest type, which was removed after the war to a nucleus depôt at Watford.[3]

(*b*) Relations with Contractors.

In addition to the firm of Messrs. John Bell, Hills & Lucas, Messrs. James Spicer & Sons, Ltd., placed their services at the disposal of the Supply Committee and were largely responsible for the extension of factories, acquisition of new factories, and the management and payment of workers.[4] The London anti-gas factories developed into two groups, under the control of these two contractors. In June, 1918, the former carried on anti-gas work in three factories, the most important operations undertaken having been canister filling and the doping and assembly of small box respirators, as well as (at an earlier date) the dipping and assembling of helmets. In June, 1918, Messrs. James Spicer & Sons had twelve factories of their own and also controlled the works of eight other firms, the work being scattered in 30 different buildings.[5] The chief operations under Messrs. Spicer were the cutting, stamping, and sewing of helmets and respirator masks, manufacturing goggles and certain component parts. Both firms were engaged on salvaging and repairing apparatus returned from overseas. The Supply Committee frequently met at the Oxford Works factory of Messrs. John Bell, Hills & Lucas, and this, together with the presence of the two manufacturers at its meetings, enabled the members to keep in specially close touch with the manufacture of appliances. This was particularly valuable in connection with the experimental work carried on or when a sudden emergency arose, calling for the provision of new appliances in a very short time.

The first helmets were simple in construction, and after the helmet had been dipped and dried, the breathing valve and tube were fixed in and the complete apparatus packed by Messrs. John Bell, Hills & Lucas.[6] With the introduction of the box respirator, the assembly

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1 Hist. Rec./R./1660/21.
2 See below, p. 75.
3 Hist. Rec./R./1660/21.
4 Hist. Rec./H./1650/13, No. 2, p. 3.
5 Appendix X.
6 Hist. Rec./H./1650/13, No. 11, pp. 6 and 7.

of the apparatus became a very important process and much attention was given to the subject. The first important assembly scheme was instituted at the factory at Nottingham of Messrs. Boots, Ltd., who had contracted for the supply of the large box respirator.[1] It was decided that the respirators should only be manufactured under the supervision of an inspection officer of the Anti-Gas Department, and on 31 January, 1916, Lieut. Sadd received instructions to supervise the respirator factory at Nottingham.[2] The small box respirator was first assembled at Messrs. John Bell, Hills & Lucas' factory in July, 1916, but other assembling schemes were established at Messrs. Boots' factory at Nottingham, the "Spurs" Ground, Tottenham, Stanstead House, Tottenham, and Fairfax Hall, Harringay.[3]

Assembling schemes were also established in connection with recovery factories.[4] After various experiments it was found that a considerable number of helmets and respirators could be repaired and re-issued. The impregnating chemicals in the helmets were recovered by Messrs. John Bell, Hills & Lucas, who erected special plant for extracting the glycerine, as none of the chemical manufacturers who were approached by the Committee were able to undertake this work successfully.[5] The apparatus was first dismantled and all parts inspected. Those which could be re-used were disinfected, washed, mended at the repairing factories, where they were finally re-assembled and very carefully graded on inspection for general service, the Home Forces, or practice only.[6] Recovery of apparatus was carried on at the Green Walk and Dockley Road Factories of Messrs. John Bell, Hills & Lucas, and at Tottenham ("Spurs" Ground Factory), under Messrs J. Spicer & Sons. There were also two helmet-repairing factories established in France, at Calais and Abbeville, from September, 1915, to March, 1918, under the Army Ordnance Department, but the necessary materials and new parts were supplied by the Anti-Gas Department.[7]

(c) SUPPLY OF COMPONENT PARTS AND MATERIALS.

Component parts were at first obtained by the appliance contractors. In this way Messrs. John Bell, Hills & Lucas provided metal breathing tubes for helmets, but from 12 August, 1915, this work was only undertaken by Messrs. J. Spicer & Sons, who made all arrangements with the manufacturers of breathing valves and metal tubes and supplied tape and elastic to the sewing factories.[8] Messrs. Spicer supplied the names of firms whom they employed to the Contracts

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1 Minutes of Anti-Gas Supply Committee (14/1/16).
2 *Ibid.*, 31 January, 1916; HIST. REC./R./1660/21.
3 HIST. REC./H./1650/12, No. 11, p. 19.
4 *Ibid.*, No. 8, p. 8, and No. 3, p. 3.
5 HIST. REC./H./1650/13, No. 11, p. 8.
6 HIST. REC./H./1650/12, No. 3, p. 4.
7 HIST. REC./H./1650/13, No. 11, p. 8; Minutes of Anti-Gas Supply Committee (27/7/17).
8 Minutes of Anti-Gas Supply Committee (12/8/15).

Branch, but the contract was made between them and the manufacturer, and any complaints as to quality were made by the Committee to Messrs. Spicer.[1] With the great increase of the number of appliances needed, this system came to an end and the contracts for parts were placed as a rule direct with the manufacturers, although some of the original manufacturers still worked through Messrs. Spicer.[2] With the introduction of the box respirators, the cutting and stitching contracts for masks were chiefly placed with firms under the control of Messrs. James Spicer & Sons.

From the end of 1915, the work of the Supply Committee chiefly consisted in the struggle to obtain supplies, but the situation became far more serious in 1917.[3] It was never possible to build up a surplus, so that any failure on the part of a contractor immediately affected the output of appliances.[4] In spite of shortage of material and ever increasing demands from G.H.Q., the Anti-Gas Department not only succeeded in meeting the needs of the British armies, but also carried out a considerable amount of work for the Admiralty and Royal Naval Air Service, and for the Allies. One of the chief steps taken to ensure satisfactory supplies was an increase in the number of the Contracts Branch's inspectors,[5] a special inspector being appointed to deal with the metal parts, which were mainly made round Birmingham;[6] special tours of inspection were undertaken by the officials of the Contracts Branch;[7] when any deliveries of any component part were continuously unsatisfactory, representatives of the manufacturers were called to a conference in London to meet the officers of the Anti-Gas Department and discuss the difficulties encountered;[8] the manufacturers were encouraged to visit the inspection depôts, where they could see the methods of inspection and learn the use to which their articles were put.[9] The Committee carefully considered the standard of rejection to be maintained by the technical inspectors, and made arrangements to use all deliveries where possible, even if slight variations or faults occurred. Thus arrangements were made to wash in London, at the manufacturer's expense, a large consignment of flannelette in which too much size had been used, rather than return it to Manchester. The inspectors were also ordered to smooth down small roughnesses in metal parts, rather than return them to the manufacturers for small defects.[10]

The difficulties of the contractors in obtaining supplies of materials were met by the Contracts Branch arranging to purchase certain necessary materials and issue them to the manufacturers at fixed

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1 Minutes of Anti-Gas Supply Committee (4/11/15 and 11/11/15).
2 *Ibid.* (10/2/16).
3 *Ibid.* (6/6/16; 3/1/17; 17/4/17; 27/7/17; 1/8/17; 17/8/17).
4 *Ibid.* (2/3/17; 3/10/17; 13/8/17).
5 *Ibid.* (2/3/17; 13/8/17; 3/10/17).
6 *Ibid.* (13/11/15; 22/11/15).
7 *Ibid.* (6 and 15/6/16; 5/2/17; 17/4/17)
8 *Ibid.* (8/5/17).
9 Hist. Rec./H./1650/12, No. 6, p. 8.
10 Minutes of Anti-Gas Supply Committee (8/3/16; 16/1/17; 8/3/17; 15/3/17).

rates. Thus, in 1917, tinplate for canisters and for metal eye-pieces was supplied, and wire gauze for canisters, elastic for masks, and buttons for satchels were also issued by the Contracts Branch.[1] It became obvious, however, that the Anti-Gas Department was seriously handicapped, even after the appointment of the special Supply Officers, by remaining under the War Office when all other similar supplies were under the control of the Ministry of Munitions.

Fabric, whether for helmets or masks, was obtained by the Contracts Branch, mainly in Manchester, where the War Office had a special organisation. Contracts for making up helmets, for wallets and satchels were also placed by the Contracts Branch with the manufacturers, and the responsibility for the proper performance of the contract, but not the technical inspection, lay with the inspectors of the Contracts Branch.[2]

Granules for the box respirators were at first manufactured by Messrs. Boots, Ltd., Nottingham, according to the formula prepared in the Department. This firm erected plant from machinery, etc., already in their possession, which was adapted for the new work. The granules were extremely difficult to manufacture to a uniform standard and complaints from the canister filling factories were frequent, while the continual pressure placed on the firm by the Committee to increase their output probably had its effect on the quality of their deliveries.[3] With the increasing demands for the small box respirator, on its issue in 1916, the Committee felt it unsafe to depend on the supply of granules from one factory only, and it was decided to start a second granule factory. This was the only factory under the direct control of the Anti-Gas Department while it formed part of the War Office. Part of the L.C.C. stores depôt at Stamford Hill was acquired and fitted up on the model of Messrs. Boots' factory by February, 1917. Before the plant was in working order a new formula for granules was introduced and further plant erected, and the new or "F" granule only was produced at Stamford Hill. Experiments were still being carried out in its manufacture at the time of the Armistice, but the maximum output reached with a day and night shift was 30 tons a week.[4]

Charcoal, used in the filling of the canisters of the large box respirator, was obtained from charcoal manufacturers, but the supplies of bone charcoal in the country were not adequate for the small box respirator. It was found that a satisfactory wood charcoal could be used and manufacture was carried out at the South Metropolitan Gas Company's works at Greenwich, under the control of officers of the Anti-Gas Department, and subsidiary factories were opened in the winter of 1917–1918 at Southend and Margate. The supply of birch wood and its conversion into logs and chips was organised, the chief centres being at Mitcham and Tonbridge. About 15,000 tons of

[1] Minutes of Anti-Gas Supply Committee (3/2/17; 20/3/17; 8/5/17; 4/7/17; 23/7/17; 26/9/17).

[2] *Ibid.* (16/6/16; 2/1/17; 9/1/17).

[3] HIST. REC./H./1650/11, pp. 30, 31.

[4] HIST. REC./H./1650/13, No. 1; No. 2, p. 9, and Minutes of Anti-Gas Supply Committee (21 and 22/9/16).

birch wood were used in the manufacture of respirator charcoal, the full output of the factories being over 20 tons of charcoal a week.[1] In August, 1918, it became necessary to provide a harder charcoal, and wood was superseded by fruit stones, nut shells, vegetable ivory, and cocoanut shell. The burnt cocoanut shell was obtained from India and Ceylon, and re-burnt and activated at Greenwich.[2] Towards the end of 1918, a contract for this highly activated charcoal was placed with Messrs. Sutcliffe, Speakman & Co., Leigh, Lancs, the only firm which seemed to have specialised in its production. Output in bulk had not, however, been attained before the Armistice, although early results showed the method to be both effective and economical.[3]

(*d*) Financial Arrangements.

Satisfactory financial relations with contractors were extremely difficult to arrange, owing to the continued urgency of the supply of anti-gas apparatus. In the first rush of the summer of 1915, no formal contracts were made with either Messrs. John Bell, Hills & Lucas, or Messrs. J. Spicer & Sons, but orders were given by word of mouth, and neither firm had time to keep an exact account of their operations. In August steps were taken to regularise the position, and it was agreed with Messrs. Spicer that contracts for goods, normally manufactured by the firm, should be placed in the ordinary way at fixed prices, but that in the case of orders for metal tubes and screw eye-pieces the firm should keep separate cost accounts to be certified by chartered accountants. The basis of remuneration was to be the actual cost, plus percentage profit and any establishment charges. It was also found to be impossible to arrange formal contract terms with Messrs. John Bell, Hills & Lucas, owing to the experimental nature of the work carried out on behalf of the Committee. The remuneration for the personal services of both Mr. Spicer and Mr. Lucas was held in abeyance,[4] but for articles jointly invented by either Mr. Spicer or Mr. Lucas, the latter was to receive remuneration from Messrs. Spicer & Sons, the approval of the Committee having first been obtained.[5] No definite agreement was reached with Messrs. John Bell, Hills & Lucas until early in February, 1916, when it was arranged that the firm should be paid 10 per cent. on actual expenditure with a maximum of £7,500 in settlement of all claims up to 31 December, 1915, but all questions as to loss of ordinary business and reinstatement of premises were waived. For work done in 1916, a contract was made on 22 February, 1916, the firm receiving 5 per cent. on actual expenditure, with a maximum of £8,000 for the whole year. The difficulty of this system soon appeared, as with the continually increasing demands for appliances, the maximum payment had been reached in November and the Treasury agreed to extend the limit to

[1] Hist. Rec./H./1650/13, No. 2, pp. 15–16; No. 11, p. 11; and Hist. Rec./H./1650/12, No. 7.
[2] Hist. Rec./R./1660/21.
[3] *Ibid.*
[4] Minutes of the Anti-Gas Supply Committee (17/8/15).
[5] *Ibid.*

£15,000. In 1917, the firm again sought revision of the contract, but nothing had been settled by the Treasury when the Anti-Gas Department was transferred to the Ministry of Munitions.[1] The latter cancelled existing contracts and suggested that instead of arranging a cost plus profit agreement, it would be more satisfactory if the firms were paid a management fee to cover all work on anti-gas appliances, to date from 3 February, 1918.[2] Before this was arranged, the Ministry of Munitions decided that it was necessary to make arrangements for keeping a more adequate check on the receipt and issue of component parts in the assembly factories of Messrs. John Bell, Hills & Lucas, Messrs. James Spicer & Sons, and Messrs. Boots, Ltd., as as the Ministry was paying the consignor contractors on the strength of receipts given by the three firms. A conference was held at the Ministry,[3] and on 10 April, 1918, it was decided that the best method of dealing with the question was the conversion of the assembly factories into national factories to be managed by the three firms as agents; the exact terms of management were thenceforward the subject of lengthy negotiation.[4]

Similar difficulties arose in the relations with other contractors who supplied component parts and materials. In the ordinary course the firms gave tenders for the goods and a sample was received and tested at Millbank, before definite contracts were placed by the Contracts Branch. The work, however, was entirely new and all workers were inexperienced. Thus, in the sewing factories, in the first instance, a large number of small box respirator masks were rejected. At the Tottenham factory between 30,000 and 40,000 were rejected as slightly defective, before the workers were sufficiently experienced. Repairs had to be carried out at another factory, and the question came up before the Committee as to what remuneration should be made to the Tottenham factory for masks spoilt during its "experimental" stage.[5] Again, the flannelette manufacturers complained that their material was rejected for flaws, which would not have mattered if the material had been put to ordinary uses. Rejections in bulk were avoided as much as possible and slight defects were remedied at the cost of the manufacturer.[6] Contracts were not renewed with firms whose deliveries were consistently bad, unless supplies were so short that the Committee was forced to employ them again.[7] Complaints as to methods and stringency of inspection were frequent, but it was not till February, 1917, that the schedules issued for anti-gas contracts contained the condition that all supplies were "to be to the entire satisfaction of the Inspecting Officer of the R.A.M.C. College, appointed by the Anti-Gas Committee."[8] Moreover

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[1] 84 P./Demands/9.
[2] *Ibid.*
[3] *Ibid.*
[4] *Ibid.*
[5] Minutes of the Anti-Gas Supply Committee.
[6] *Ibid.* (3 and 15/3/17.)
[7] *Ibid.* (10 and 23/2/16; 18/12/16; 28/7/16).
[8] *Ibid.* (20/2/17).

the need for further provision of defensive apparatus against an expected new offensive on the part of the enemy was at times so urgent that orders were placed without waiting for tenders to be received. This occurred in March, 1917, when orders were placed for two million extension boxes for the small box respirator, the firms only being required to submit costings.[1] When the costings were examined, a variation of from £1 0*s*. 3·99*d*. to £2 0*s*. 1*d*. per gross for solid drawn boxes appeared, since the methods of manufacture and materials used were those available at the moment and differed in nature and suitability.[2] Two months later, when tenders were received for small expiratory valves, orders were placed at prices varying from £5 5*s*. 0*d*. to £7 10*s*. 0*d*. per 1,000, owing to the necessity for the demand being met quickly.[3]

III. Inspection.

With the development of more and more elaborate anti-gas appliances, a minute inspection at all stages of manufacture became necessary and considerable difficulty was experienced in maintaining a strict standard of inspection, without delaying the issue of the finished article. In spite of its importance, the system of inspection developed somewhat by chance. A percentage of the daily output of the anti-gas factories was from the first tested by the Royal Army Medical Corps officers and subjected to laboratory tests and tests on the man,[4] but the extensive use of textiles brought the Anti-Gas Department into close touch with the Royal Army Clothing Department, which gradually became responsible for the inspection of fabric and component parts.

Until April, 1918, all textile materials were inspected by the Royal Army Clothing Department at Pimlico. The deliveries were compared with approved samples and each bale of cloth was inspected by male viewers of the Royal Army Clothing Department.[5] The testing of flannelette was fairly simple, but the system was not completely satisfactory, and early in 1916 the Anti-Gas Committee received various complaints from firms making up helmets that their helmets were rejected on account of flaws in the materials. The Committee therefore asked the helmet manufacturers to return any really defective bales issued to them, a credit being allowed them for this and a corresponding claim made on the flannelette manufacturers.[6] On the introduction of the box respirator, further difficulties arose over the inspection of the proofed material used for the mask. This was delivered by the War Office Cotton Textiles Department at Manchester without inspection direct to the dryers and proofers, so that when it was inspected at Pimlico both for flaws and transparencies, it was impossible

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1 Minutes of the Anti-Gas Supply Committee (13/3/17).
2 Contracts/R./5221.
3 Contracts/Anti-Gas/85.
4 HIST. REC./H./1650/13, No. 2, pp. 13, 19.
5 HIST. REC./H./1650/12, No. 6, p. 1.
6 Minutes of the Anti-Gas Supply Committee (4/2/16).

on rejection to fix the responsibility. On 15 March, 1917, the Committee decided that if the proofers proofed weak material, they would be held responsible.[1] In March, 1918, owing to the issue of helmets being finally discontinued, further space for inspection was available in the Anti-Gas Department's depôt at 205, Camberwell Road, S.E., and it was decided to take over fabric inspection from the Royal Army Clothing Department.[2] At the same time it was arranged that the Cotton Textiles Office at Manchester should inspect the mask fabric for weaving flaws before delivery to the proofers.[3]

Inspection of the proofed fabric was originally conducted by passing the material over rollers in front of electric lights of 120 c.p. These were subsequently replaced by lamps of 600 c.p. with reflecting mirrors. The inspection of fabric became more stringent under the Anti-Gas Department; rejections became so frequent that various experiments were carried out and it was found that a less exacting standard could be allowed. This was adopted in October, 1918, and the rejection in bulk fell from 5 per cent. to ½ per cent. After inspection over the rollers, a sample of about 18 in. square, taken from about 5 yards within either end of the roll, was cut off for the permeation test.[4]

Other parts of anti-gas apparatus made of textile fabrics were inspected until August, 1917, by the Royal Army Clothing Department, first at Bessborough House and then at 205, Camberwell Road, with the exception of respirator masks. The Anti-Gas Department took over the inspection of these articles, which included helmets (on leaving the sewing factories), and such articles as wallets and satchels. The civilian viewers of the Royal Army Clothing Department were replaced by women examiners under a Lady Superintendent working under the orders of the inspection officers at the main depôt at 130, New Kent Road, S.E.[5]

The inspection of component parts was only gradually developed. On the introduction of the P.H. and P.H.G. helmets, the manufacturers delivered the parts without inspection to Messrs. John Bell, Hills & Lucas' factory. As early as September, 1915, it was found that a considerable number of parts could not be used for assembly at all, but the matter became more serious when helmets were returned from overseas in the following month, on account of defective breathing valves. The valves had been provided by Messrs. J. Spicer & Sons, who, on 27 October, 1915, undertook to arrange for a closer inspection before delivering the valves.[6] It became clear, however, that an official inspection of parts was necessary, and on 4 January, 1916, the Committee informed Messrs. John Bell, Hills & Lucas that Royal Army Clothing Department viewers would shortly be taking up work

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[1] Minutes of the Anti-Gas Supply Committee (15/3/17).
[2] HIST. REC./H./1650/12, No. 6, p. 2.
[3] *Ibid.*, p. 5.
[4] HIST. REC./H./1650/12, No. 1.
[5] Minutes of the Anti-Gas Supply Committee (18/12/15), and HIST. REC./H./1650/12, No. 6, p. 2.
[6] Minutes of the Anti-Gas Supply Committee (26 and 27/9/15 and 27/10/15).

at Oxford Works.[1] The number of parts to be inspected increased so rapidly that the space at Oxford Works was insufficient, and the firm was authorised in March, 1916, to take premises at 130, New Kent Road, as an inspection depôt.[2] The Committee decided that this should form a central inspection depôt for all component parts, the first step being that manufacturers of metal parts in London were ordered to deliver goods to the depôt on and after 25 April, 1916, instead of to the manufacturers.[3] The need for closer control of the inspection of parts by the Anti-Gas Department was still further emphasised after the introduction of the small box respirator with its large number of parts, and in January, 1917, the Department took over the responsibility for, and control of, inspection at the depôt. The Royal Army Clothing Department ordnance officer and the civilian viewers were replaced by an anti-gas officer and 8 non-commissioned officers, but the depôt was under triple control for some months, as all matters of issues and receipts still remained under the Royal Army Clothing Department staff, while the actual work was carried out by the inspecting staff of Messrs. John Bell, Hills & Lucas, consisting of 774 women under a forewoman and 24 assistant forewomen, together with 7 male hands.[4]

In July, 1917, the Anti-Gas Department took over the depôt from the firm entirely, and both the Royal Army Clothing Department staff and the women inspectors were transferred to the control of the anti-gas officer, though payment of wages was still made by the Royal Army Clothing Department. New buildings were also taken over, store depôts for approved goods being opened at Hick's Warehouse, Falmouth Road, and at 202-208, Westminster Bridge Road, while premises at 143, Clapham Road, were devoted to the inspection of oval containers.[5] In the spring of 1918 two factories were opened in South London for the manufacture of emergency jackets, and departments for accounting and preliminary inspection of the component parts, cellulose, and canvas, were opened at the factories as sub-depôts of 130, New Kent Road. At one of these, formerly the National Filling Factory in Sumner Street, Southwark, the inspection of leather gauntlets, cotton gloves, and oiled suits was also carried on.[6] The inspection depôts in London supplied all the group of London anti-gas factories with component parts, but at Messrs. Boots' Nottingham factory a separate system was developed, and the accounting and inspection of parts was there carried out in close connection with, and under the control of, the anti-gas officer in charge of the assembly factory.[7]

Inspection of component parts was divided into three operations: (*a*) counting, to check the contractors' invoices; (*b*) visual examination;

[1] Minutes of the Anti-Gas Supply Committee (4/1/16).
[2] Hist. Rec./H./1650/12, No. 8, p. 2.
[3] Minutes of the Anti-Gas Supply Committee (29/2/16; 8/3/16; 19/4/16).
[4] Hist. Rec./H./1650/12, No. 8, p. 1.
[5] *Ibid.*, pp. 1, 2.
[6] Hist. Rec./H./1650/12, No. 8, p. 2.
[7] Hist. Rec./H./1650/11.

(c) pressure and vacuum testing of containers, and the components forming the respiratory passage of the small box respirator. A definite scheme of inspection for each part was drawn up for the use of the inspectresses. All rejects were subject to a second examination by check examiners before being returned to the manufacturers, but only 10 per cent. of the approved parts were as a rule subjected to re-examination.[1] Pressure testing of angle tubes, rubber connections and containers, and vacuum testing of valves was carried out entirely at the assembly factories until May, 1918. Plans had been made before this for the erection of the necessary machinery at the inspection depôt, but the installation was not only delayed, but the original requisition was cut down by half. In consequence only a certain number of these parts could be completely inspected before issue from the depôt. They were reserved for issue as spare parts for overseas and the Italian gas service, while the partly tested parts were issued to the London assembly factories.[2] Inspection of celluloid discs, horse respirators, mounted valves, and splinterless circles was carried out by anti-gas officers at the manufacturers' factories before delivery.[3]

The inspection of helmets, when assembled, was entirely in the hands of Messrs. John Bell, Hills & Lucas, with the exception of the laboratory tests, until early in 1917, when the final inspection was placed under the control of an anti-gas officer, although the firm still provided and trained the inspectresses.[4] On the introduction of the small box respirator, which was manufactured under the control of anti-gas inspection officers, the department organised a much more minute inspection at every stage of manufacture. The subordinate inspection staff was, however, still as a rule paid by the manufacturers. At Messrs. John Bell, Hills & Lucas' factories the inspecting staff was divided into three classes: (a) the military inspection staff; (b) a semi-military inspection staff, and (c) civilian inspectresses and check inspectresses. The second class consisted of a number of girls, picked from the factory workers, who wore a special factory uniform. They supervised certain important operations and assisted the military staff, but they had no disciplinary powers. They were paid by the firm, but came under the direct control of the officer in charge. The third and largest class was paid by the firm and only came under military control in so far as the standards for inspection were laid down by the officer in charge.[5] At the other small box respirator factories in London, the inspecting staff was engaged by Messrs. James Spicer & Sons, who, in August, 1916, chose a number of educated women, who were trained by an anti-gas officer, and drafted as needed to the different factories. They were provided with scarlet uniforms and were known as "red-coats." They were paid by Messrs. James

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[1] HIST. REC./H./1650/12, No. 1.
[2] *Ibid.*, No. 6, pp. 3, 4.
[3] *Ibid.*, p. 3; Minutes of the Anti-Gas Supply Committee (25/10/16; 22/1/17; 23/7/17).
[4] *Ibid.* (19/5/17; 9 and 23/7/17).
[5] HIST. REC./H./1650/12, No. 8, pp. 9, 10.

Spicer and received instructions from the officer in charge.[1] In some factories, carried on by other firms under the control of Messrs. James Spicer & Sons, the firms also appointed an inspecting staff. Thus at the Tottenham mask factory the manufacturers appointed examiners, known as "blue-coats," who undertook the inspection of the intermediate sewing stages.[2]

The military inspection staff consisted at each factory of the officer in charge and a staff of specially trained privates of the Royal Army Medical Corps, who were raised to the rank of sergeant. Their work consisted of check inspecting. As the number of factories increased, the best "red-coats" were picked out, raised in rank and pay, and undertook the sergeants' duties. Officially they ranked as military supervisors of inspection, but they were interchangeable on the staff with the men. A lady superintendent was appointed at the same time to be in charge of the supervisors and "red-coats."[3]

The inspection of the repair depôts in France was under the control of the women superintendents, who were gazetted to the Royal Army Ordnance Department.

IV. Summary.

The success accompanying the work of the Anti-Gas Department was largely, and throughout its history, dependent on two factors. The most important was the research work carried on at the Royal Army Medical Corps laboratories at Millbank and University College, and so successful was this branch of the department that it was claimed that no gas was used by the Germans, in any considerable quantity, after the first attack in April, 1915, against which the British troops were not already in possession of sufficient protection.[4]

The second factor was the anxiety of all the different organisations concerned to co-operate in the provision of the most effective protection that could be devised. This co-operation was very largely facilitated by the unity of control which existed in respect of research and supply.[5] Thus the research work in the laboratories was supplemented both by the work of the Physiological Committee of the Royal Society on the effects of poison gas and by the experience gained by the Chemical Advisers attached to General Headquarters in France and to each division. In the same way, the different functions of the Royal Army Medical Corps, Royal Army Clothing Department, Royal Army Ordnance Department, and the Contracts Branch were co-ordinated in the Anti-Gas Supply Committee.

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[1] HIST. REC./H./1650/13, No. 11, p. 3, and Minutes of the Anti-Gas Supply Committee (23 and 25/8/16).
[2] HIST. REC./H./1650/12, No. 4, p. 10.
[3] HIST. REC./H./1650/13, No. 11, p. 3.
[4] HIST. REC./H./1650/13, No. 12, p. 2.
[5] See above, p. 1.

The appliances manufactured under the auspices of the Anti-Gas Department up to 11 November, 1918, were as follows :—[1]

Flannel Hypo Helmet	2,500,000
" P." Helmet	9,000,000
" P.H." Helmet	14,000,000
" P.H.G." Helmet	1,700,000
Horse Respirators	700,000
Goggles	6,000,000
Large Box Respirators	200,000
Small Box Respirators, complete	13,500,000
Small Box Respirators, spares	4,500,000
Box Extensions	1,000,000
Filter Jackets	1,000,000
Green Band Box Respirators, complete	55,140
Green Band Box Respirators, spares	122,000
Impregnated Leather Gloves	157,000
Anti-Mustard Gas Suits	60,000
Small Box Respirators, recovered and re-issued	2,082,000
Pigeon Basket Covers	2,000

When the P.H. helmet was issued the aim of the department was for each man to carry two helmets, but when the small box respirator became the chief defensive apparatus, a helmet was carried as a second means of protection, until February, 1918, when the box respirator became the sole apparatus issued.[2] With regard to the supply of anti-gas apparatus, of which over 50,000,000 complete articles were issued, it should be noted that these involved the supply of a large number of parts. Thus 105 components went to the composition of one small box respirator, so that the number of small articles involved made accounting extremely difficult and the accurate counting of consignments received practically impossible.[3]

In the anti-gas factories no stoppage of work took place for industrial reasons, although at times the shortage of material and component parts seriously interfered with their regular working and output. The work in these factories was largely carried out by women, about 12,000 being employed in the factories and depôts, either directly under the department or controlled by it, including both the granule and charcoal factories.[4]

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[1] HIST. REC./H./1650/13, No. 2, p. 12.
[2] HIST. REC./H./1650/13, No. 2, p. 7.
[3] HIST. REC./H./1650/12, No. 6, pp. 3, 8.
[4] HIST. REC./H./1650/9, No. 11.

CHAPTER VII.

SMOKE AND INCENDIARY MIXTURES.[1]

I. Developments in the Use of Smoke and Incendiary Mixtures.

Both smoke-producing and incendiary substances were used spasmodically in the early days of the war; but it was not till the summer of 1916 that the destructive powers of incendiary bombs began to be fully recognised and that their special use from aircraft for firing buildings, forests, or crops, or for air bursts in attack on kite balloons was developed.[2] Similarly, while smoke screens were extensively employed during the Battle of Loos (September, 1915) and the troops improvised various methods of smoke production, it was not until a full year had passed that the tactical value of smoke screens was realised to the full.

The earliest type of aerial incendiary bomb was a tin container charged with petrol, the output of petrol bombs from August to December, 1914, being 1,299. At the end of 1914, other types in use were a 20-pdr. filled with incendiary composition and powder, a second 20-pdr. containing T.N.T. and petrol, and a 10-lb. bomb filled with carcass powder; but petrol and powder bombs were obsolete by the middle of 1917.

Among the experiments made with a view to finding some means of speedy retaliation for the German gas attack of April, 1915, carbon bisulphide and phosphorus bombs were tested for their incendiary effect (19 May, 1915), and by the middle of June further experiments with grenade fillings had indicated phosphorus as being effective in producing a rain of fire with dense white fumes. About this time a demand had arisen for a mixture which would produce smoke clouds for screening the movements of troops and through which they could advance, and on 23 June, 1915, the use of phosphorus for offensive purposes was approved. Three days afterwards 1,000 grenades containing amorphous phosphorus were ready and packed, and arrangements were made whereby they could be turned out at the rate of 1,000 a day, with an increase, if required, to 10,000 a day. By the middle of August more than 10,000 had been filled. These smoke-producing grenades were sent out in fairly large and regular quantities, and unlike the majority of the early stop-gap chemical grenades they survived in service use. The type used—a 3-in. by 3-in. container filled with red phosphorus—was known as the "P" grenade. By the end of 1915, 20,000 had been filled and sent

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[1] Hist. Rec./H./1650/9 and H./1650/10.
[2] Vol. XII, Part II.

to the front and further supplies were continued. Further consideration was given to the question of smoke producers for land service by the Scientific Advisory Committee shortly after its formation (23 June, 1915), but none of the various mixtures which were tried gave results comparable with those obtained from phosphorus when equal quantities of the materials were employed. Steps were accordingly taken to increase the supply of phosphorus.

On 27 July, 1915, a sudden demand was received from France for an incendiary grenade to be thrown by hand or catapult, for the purpose of destroying the long grass in front of the trenches which afforded cover to the enemy. This was the first request for an incendiary missile.

Tins 3 ins. by 3 ins. (diameter) filled with white phosphorus and paraffin oil and petrol were supplied, about 50,000 being produced and sent to the front. These were known as the "Threlfallite" bombs. White phosphorus was used in preference to red in consequence of the uncertainty of ignition which had been experienced with the latter.

When the employment of phosphorus was first sanctioned it appears to have been with a view to both incendiary and smoke-producing purposes. It was, however, as a smoke producer that it was principally valued later. Whether the red amorphous phosphorus or the much more inflammable "white" molten phosphorus should be used was for long under discussion. For smoke production the scattering effect of the red phosphorus bomb was not desired, as it was a source of danger to advancing infantry and to wounded lying in the area covered, and another objection to its use was the difficulty of ensuring suitable detonation; yet the presence of white phosphorus in the British trenches was a source of danger, and the conversion of white phosphorus into red is a process which occupies a considerable time.

Many experiments were made with different types of phosphorus grenades during December, 1915, and January, 1916, and while these were in progress white phosphorus, known as "Fumite," was filled as a temporary measure into two types of bomb. Of one of these 20,000 were ordered, while a contract was placed for the supply of 150,000 of the other, at the rate of 12,500 a week, by the end of 1915. Eventually a decision of the General Staff against the use of white phosphorus occasioned these two types of fumite grenade to be abandoned at the beginning of 1916.

The first experiments with phosphorus in artillery shell were carried out on 9 August, 1915, and in December a request was received for 4·5-in. smoke shell for screening distant observation posts.

Early trials were made of the employment of phosphorus in Stokes mortar bombs. On 31 August, 1915, white phosphorus was tried, but the recommendation of the Scientific Advisory Committee, on 2 September, in favour of red phosphorus necessitated further trials. By the beginning of October, 8,000 3-in. Stokes bombs filled with red

phosphorus had been prepared, and a further 48,000 had been ordered by the end of 1915, at the rate of 4,000 a week. The amount of phosphorus in each bomb was 2·2 lb. Shortly after this the military authorities decided that chemical fillings which included phosphorus should be used in the 4-in., and not the 3-in. Stokes bombs. As a result of this change further experimental work was needed to ascertain the most suitable bursting charge. This was not completed till the spring of 1916, though papier-maché bombs had been improvised to meet an urgent demand received from France on 22 August, 1915, for a 4-in. Stokes bomb containing red phosphorus. This demand was the first formal request for smoke ammunition to be used in Stokes mortars, and in response to it smoke bombs were issued in time for use in the Loos offensive.

With the introduction of the Threlfallite bomb the tactical value of longer range projectiles for incendiary purposes became obvious, and the use of trench mortar bombs and artillery shell containing incendiary compositions was considered for setting fire to buildings and other objects some distance behind the enemy lines. On 19 July, 1915, it was suggested that bombs should be filled with the well-known thermit mixture of iron oxide and aluminium (commonly called "Thermit"), mixed with phosphorus. Experiments were accordingly made and the incendiary value of such bombs was found to be high when the explosive ophorite was used as a bursting charge. This explosive—a mixture of potassium perchlorate and magnesium powder—had been discovered a short time previously by Professor Thorpe during the course of an experimental investigation of suitable mixtures for the filling of flares. Its use for detonating 4-in. Stokes bombs was approved in principle in March, 1916, and its discovery made possible the successful utilisation of thermit as an incendiary agent in trench mortar bombs. At the beginning of June, 1916, as a result of further satisfactory experiments, 2-in. trench mortar thermit incendiary bombs and 4-in. Stokes thermit incendiary bombs were approved, and steps were taken to supply 10,000 of each of these to meet the urgent requirements of the army in the field.

In the summer of 1916 an urgent demand was also received for supplies of incendiary shell, and some 4·5 in. howitzer shrapnel shell were filled with thermit and ophorite for immediate use, but it was not found possible to produce a really effective 4·5-in. or 6-in. thermit incendiary shell. Experiments were also made on the use of thermit in aircraft bombs.

In 1916, prior to the Somme offensive, phosphorus bombs were used from aeroplanes for setting fire to enemy kite balloons. The type originally used was superseded in the autumn by a larger bomb filled with a mixture of red and white phosphorus, but these were rendered obsolete later by the development of incendiary ammunition or the destruction of balloons.[1]

[1] Vol. XII, Part II.

Further experiments were made with incendiary compositions, and in March, 1917, approval was given for the use of D.W. (Dr. Whiteley) mixture, and this, together with thermit, continued in service use. Experiments were also carried out with permite as a smoke producer.

In August, 1915, the British authorities decided to employ large flame projectors for scattering burning oil in retaliation for the German use of flammenwerfer at Hooge, on 30 July, 1915. One such projector was accordingly designed and had a range of 110 yards, *i.e.*, nearly double the range of the large German apparatus. It was first used in July, 1916, in the opening phase of the Somme battle. As an improvement on this, bombs filled with oil were used in the Livens projector. It was found possible to pitch a 3-gallon can filled with Persian distillate 200 yards. These were used on the night of 25 July, 1916. A second and improved pattern was made with a range of 350 yards. These drums were filled with 5 lb. cotton waste in the form of balls saturated with a mixture of one part of a heavy Mexican petroleum residue with three parts of Persian distillate, and were fitted with ophorite bursters. These drums were filled and sent to the front in large numbers and were used with remarkable success preliminary to the attack in 1917 on the Messines Ridge.[1]

Meanwhile, further developments had taken place in the use of phosphorus. At the beginning of 1916 a strong prejudice still existed at the front against white phosphorus grenades, and throughout practically the whole of 1916 the only phosphorus grenade in supply was the " P " bomb, filled with red phosphorus. On the results of comparative trials with 4-in. Stokes bombs, which showed that white phosphorus was the more effective form to use in these projectiles, and that it had valuable offensive properties upon a burst in the air, the use of white phosphorus was, however, approved for this weapon on 8 April, 1916. At this time the improvised red phosphorus bomb with cardboard casing was still being issued. The first deliveries of Stokes bombs filled with white phosphorus were made during August, 1916, but results as regards smoke effect were disappointing and supplies of red phosphorus were again demanded.[2]

The tactical value of smoke screens was clearly realised, not only by the army, but also by the navy, who had been experimenting with phosphorus burners and other smoke-producing devices to be carried on ships, since at least as early as January, 1915. In order that duplication of experimental work might be avoided and intercommunication of results facilitated, a conference between the Superintendent of Research, Woolwich, and a representative of the Admiralty Board of Invention and Research was held in the summer of 1916. In October, 1916, the use of phosphorus in shell as well as in burners was recommended by the navy and a floating smoke buoy was introduced in 1917. For many naval purposes white phosphorus was used.

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[1] For further details of the development of flame projectors see Vol. XI, Part I, pp. 96–100.

[2] HIST. REC./H./1640/1.

In September, 1916, as a demand had been received from France for artillery smoke shell, the filling of 4·5-in. steel shell with white phosphorus was begun, and at the end of 1916 18-pdr. shell were also filled with this material.[1]

About the end of 1916, as a shortage of phosphorus seemed probable, experiments were made with a variety of smoke mixtures in Stokes bombs and artillery shell. The superiority of phosphorus over most other substances was recognised, but alternatives were recommended in case of need. It did not, however, become necessary to use them, and phosphorus remained throughout the war the only service filling for smoke shell.

At the beginning of 1917, the demands from the War Office for projectiles filled with phosphorus were for 4·5-in. and 18-pdr. shell and 4-in. Stokes bombs filled with white phosphorus, and for "P" grenades and 4-in. Stokes bombs filled with red phosphorus. In March, 1917, the filling of rifle grenades with white phosphorus also began. Admiralty demands were for supplies of white phosphorus in wedge form and for 4-in., 5-in. and 6-in. naval shell filled with white phosphorus. Naval smoke producers other than phosphorus were provided by the Admiralty.

On 21 November, 1917, the Director of Gas Services informed the Chemical Warfare Committee that in future phosphorus would be used entirely for smoke production and not as an agent of offence, as had sometimes been the case in the past. Accordingly the Committee recommended the use in the 4-in. Stokes steel bomb of a mixture of red and white phosphorus as being more suitable for the production of a smoke cloud than either white or red phosphorus by itself.

In the autumn of 1917 the demands from France for shell and bombs filled with phosphorus were rapidly increasing, and during 1918 the War Office and Admiralty demands became so heavy that it was not found possible to meet fully a demand of 300 tons of phosphorus for continuous phosphorus burners which were needed by the Air Board, though 50 tons was supplied for the purpose.

II. The Supply of Phosphorus.

In arranging for the supply of smoke and incendiary mixtures the chief problem which had to be solved was how to obtain an adequate supply of phosphorus.

"White" phosphorus is obtained from phosphate rock by electro-thermal smelting in large furnaces, and by a further heating process this can be converted into the "red" amorphous phosphorus. Only one factory for the production of phosphorus existed in this country at the outbreak of the war, and Messrs. Albright & Wilson, of Oldbury, who owned this factory, had practically a monopoly of the trade not only of this country but of the world. Throughout the war our supplies were obtained from this firm, who on behalf of the Government made extensive additions to their existing plant.

[1] M.C. 864.

Towards the end of 1915, in order to meet the demands likely to be made for phosphorus for war purposes, the Company increased their plant both for producing phosphorus and for converting white phosphorus into red, thus increasing their works capacity by about 50 per cent. In November, 1916, in view of the increasing demands of the War Office and the probable demands of the Admiralty, the Ministry decided that an entirely new plant for phosphorus for an output of 28 tons per week must be put down and a site at Wolverhampton, near Oldbury, was selected so that the plant might be administered and operated entirely by Messrs. Albright & Wilson. Negotiations were entered into with the firm early in December[1] and they accordingly proceeded to design and order the plant. Output commenced on 31 June, 1917, and shortly afterwards it was decided to double the capacity of the plant as the Admiralty orders then placed with Messrs. Albright & Wilson were making considerable demands upon the existing capacity. As the terms of the agreement for the original plant had not yet been settled, two contracts were drawn up to cover the whole of the extensions. The first, covering capital expenditure, was signed on 20 July, 1917. The Ministry thereby bore the cost of the plant, which remained the property of the State, and the Company had an option of taking over at an agreed figure either the whole or part of the plant at the close of the war. Prices on this contract were on a sliding scale, varying with the cost of the raw material, phosphate rock. The second contract, dated 29 August, 1917, covered the provisions made for supplies of phosphorus and was intended to establish a practical control over the industry.[2] In order to safeguard supplies pending production from this new factory, 150 tons of red phosphorus were purchased from France. This proved to be mostly in powdered form and had to be used in admixture with white phosphorus.

In the early part of 1916 the question of reducing and regulating the trade consumption of phosphorus was considered; but Messrs. Albright & Wilson undertook to give priority to all war requirements, and the allocation of supplies to the trade was accordingly left to the firm. In December, 1916, a review of the amounts of phosphorus supplied to the home trade showed that the quantity available for purposes other than service use was strictly limited to 55,000 lb. weekly, and that the demand for its use in certain home products, such as baking powder, was increasing. It was decided that any further restriction in the use of phosphorus must necessarily fall upon the match trade, but that no immediate steps in that direction were needed.

In the summer of 1917, however, the increasing demands for phosphorus for war purposes necessitated some form of central control. Since the Chemical Supply Section was responsible for the administration of 75 per cent. of the output, and also for the provision of the new factory at Wolverhampton, it was decided that all questions relating to phosphorus and all orders should be transmitted to Messrs. Albright & Wilson through them. With the agreement of the

[1] HIST. REC./R./1650/33.
[2] See below, p. 88.

Company a system of control was evolved whereby all quantities were rationed under permit, whether they were intended for trade use or for the manufacture of munitions for the navy and the army. At the same time, the Department also became responsible for the purchase of the phosphate rock and for the supply of electric powder to the Wolverhampton Factory. These were charged at fixed rates to Messrs. Albright & Wilson who sold back the resultant phosphorus at fixed rates instead of on the former sliding scale basis. This form of control was put into force on 1 July, 1917, and continued till the end of the war.

Most of the work of charging projectiles with phosphorus was carried out at the works of Messrs. Albright & Wilson, who undertook all the charging of white phosphorus, while the filling and assembling of smoke shell was executed at the Royal Ordnance Factory, Woolwich, and the assembling of white phosphorus bombs at the National Filling Factory, Watford, No. 1. The early work with red phosphorus grenades was, however, undertaken by a contractor, the Hammersmith Distillery Company, and the charging of the containers for 4-in. Stokes bombs with red phosphorus was also carried out by the Company. They also undertook to assemble the grenades, but after a few months this work was transferred to a special factory at Brook Green, which was operated by another contractor.

At the close of hostilities output had reached 85 tons of phosphorus per week.[1] There was then a stock of about 350 tons of white and 50 tons of red phosphorus, and with the phosphorus contained in filled shell and bombs the total quantity available at the end of the war amounted to about 800 tons.

The following figures give the total numbers of shell and other containers which were filled with phosphorus for the three Services.

Land Service.	
Fumite and Threlfallite Grenades	120,000
P. Grenades (R.P.)	1,519,902
2-in. Trench Howitzer Bombs (W.P.)	1,700
4-in. Stokes Bombs (W.P.)	47,056
4-in. Stokes Bombs (R.P.)	122,751
Nos. 27 & 35 Hand and Rifle Grenades (W.P.)	1,730,383
18-pdr. Containers (W.P.)	1,531,535
4·5-in. Shell (W.P.)	498,778
Experimental Projectiles	3,702
Naval Service.	
4-in. and 6-in. Shell (W.P.)	15,385
3-in. Shrapnel (Anti-Aircraft)	1,056
Air Service.	
40-lb. Conglomerate Bombs	5,110
3-in. Target Bombs	30,446
Linthune Bombs	4,000
	5,631,804

[1] Hist. Rec./R./1650/35.

The total production of both forms of phosphorus for the whole of the period between June, 1915, and December, 1918, amounted to 6,083 tons. The total cost of the whole phosphorus venture, including plant, production, and charging, was approximately £1,000,000.

III. Miscellaneous Smoke and Incendiary Materials.

Of the substances required other than phosphorus, one of the chief was the incendiary material thermit. Supplies of this were obtained from Thermit, Ltd., Messrs. Tiklen, Smith, and Mr. C. Vautin, at prices ranging from £95 to £150 per ton. Permite was obtained from the Perchlorate Safety Explosives, Company, Ltd., at 2s. per lb. Ophorite, which served as an initiator for thermit, was produced at H.M. Explosives Factory, Watford, as was also D.W. Composition. Various smoke powders were also made at H.M. Explosives Factory, Watford, and incendiary bombs were filled and assembled from July, 1916, onwards at the neighbouring Trench Warfare Filling Factory, Watford, No. 1.[1] Some incendiary bombs were also filled at the Royal Ordnance Factory, Woolwich.[2]

The aluminium powder used in the production of smoke powders was supplied by the British Aluminium Company and Aluminium Corporation, Ltd., and certain quantities of fine powder were also purchased in the United States. A control order covering aluminium powder was issued on 21 July, 1916, and the demand became so great that at the beginning of 1917 an appeal for the utmost economy was issued and it was arranged that its use should be rigorously controlled. The ration allotted for the production of smoke powders, etc., however, proved ample for this purpose.[3] Magnesium powder, which was used in incendiary compositions, was not produced in this country before the war, but a company for its production was formed under the name of the Magnesium Metal Company. Purchases were also made from time to time from Canada and the United States.[4]

IV. Signals.

The use of smoke for signals developed rapidly during the first two years of the war. During the autumn and winter of 1915, various patterns of triple smoke cases were developed. These consisted of three " candles " in canvas-covered cardboard cases, so connected as to burn in succession with a view to ensuring as long a duration as possible.[5] Contracts for them were placed with certain firework firms between September and December, 1915.[6] The chief difficulty arose out of the provision of orpiment of which the candle at this time consisted. The known sources of supply were strictly limited. Commercial " red " orpiment or realgar was less satisfactory than yellow orpiment; but the sole source of this latter was a single company, the British Mining and Metal Company, formed in 1905 to acquire the mineral and metallurgical department of Frederick Boehm, drug and

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1 HIST. REC./H./1600/9. 2 Vol. XII, Part II.
3 X. 237/21. Review of Work of High Explosives Contracts Branch (March, 1917—March, 1918).
4 X. 237/21. 5 T.W. 2115. 6 T.W./Contracts/909, 1507, 1659.

chemical merchant. This company controlled the Bedford Mines, Tavistock and Drakewell Mines, Cornwall, and until January, 1916, undertook experimental work in connection with smoke candles; but they were unwilling to manufacture the cases in bulk.[1] Meantime, the chief contractors for the cases secured adequate supplies of orpiment for their immediate orders,[2] while two or three firms of firework manufacturers investigated the use of substitutes.[3] Ultimately, a new single type of case filled with "S" mixture was substituted for the triple case with orpiment candles and came into bulk supply in May, 1916.[4]

Similarly, the main problem in the production of signal lights and fireworks lay in the supply of materials. Actual manufacture[5] was undertaken by the established firework firms, whose commercial market, largely Continental, had practically disappeared with the outbreak of war. The knowledge and skill of these makers and their operatives was often hereditary. The capacity of the larger makers was at first utilised for firework production by the War Department and the Admiralty, while the smaller firework makers of Yorkshire turned over temporarily to the filling of grenades in the autumn of 1915. The pyrotechnic industry was, however, of strictly limited extent, and in 1916, when the development of aircraft signals gave rise to new and unprecedented demands, the work of filling flares and other fireworks was undertaken by the National Trench Warfare Filling Factory at Fulham with considerable success.[6]

Organisation of the supply of the chief ingredients was a much more serious problem. Red lights were based upon strontium carbonate, green lights upon barium chlorate. British firework makers had long been accustomed to purchase these from German merchants and attempts to secure deliveries from France and Sweden met with indifferent success. There were heavy deposits of barium and strontium at Yate, about 10 miles from Bristol, but these had been under German control, and were worked with plant of German origin. It had been the practice to export the salts. Thus, for instance, strontium carbonate had been extracted from the sulphate deposits and sent to Germany or America for conversion into the strontium nitrate ultimately used by the British firework makers in the production of red lights. The Yate Chemical Company, which had purchased the freehold of the Yate works in June, 1914, re-equipped them for the purpose of making various salts; but it was not until firework manufacture began at the National Factory, Fulham, that the Department took an active part in organising supplies of materials. Direct contracts were then placed with the Yate Chemical Company and control over its operatives was exercised through a resident engineer. At the same time, two new sources of production were found at home in order to break down the previous monopoly.[7]

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[1] T.W. 2131, 8661, 8961 (I). [2] T.W. 3720.
[3] T.W. 8961 (I). 2113, T.W./Contracts/1507.
[4] T.W. 8961 (I).
[5] For a more detailed account of firework manufacture, see HIST. REC./H./1650/5, and T.W. 8961 (I) and (II).
[6] See Vol. XI, Part I, p. 125. [7] T.W. 6166, 8675, 8961 (I).

APPENDICES.

APPENDIX I.

(CHAPTER I.)

Table showing the Chief Chemical Substances used for Offensive Purposes during the War.

Code-Name.	Chemical Description.	Introduction into British Service.
S.K. (South Kensington)	Ethyl iodoacetate ..	Bulk manufacture began May, 1915.
Fumite	(White) phosphorus ..	Approved for service, June, 1915.
Red Star	Liquid chlorine ..	First issued, July, 1915 ; first used, September, 1915.
Hillite	Capsicine and magnesium carbonate.	Experimental, 1915.
White Star	Liquid chlorine and phosgene.	Adopted in cylinders, January, 1916.
C.G. (Collongite or Lancastrite).	Phosgene or carbonyl chloride.	Used in White Star ; then in C.B.R. ; introduced in Livens drums and trench mortar bombs, Spring, 1917 ; in artillery shell, late 1917.
P.S. (Port Sunlight) ..	Chloropicrin	Adopted April, 1916.
C.B.R.	C.G. and arsenious chloride (B.R.).	Recommended in principle, May, 1916 ; shell-charging began, September–December, 1916.
J.L. (Jellite)	Hydrocyanic (Prussic) acid, chloroform and triacetyl cellulose.	Authority to store, March, 1916 ; to use, July, 1916.
Green Star	Sulphuretted hydrogen (Two Red Star) and P.S.	First issue in cylinders, July, 1916.
J.B.R.	J.L. and arsenious chloride.	Adopted pending production of V.N., October, 1916.
V.N. (Vincennite) ..	Hydrocyanic acid, arsenious chloride, stannic chloride and chloroform.	Approved as a substitute for J.L., October, 1916 ; issue began April, 1917.
N.C.	P.S. and stannic chloride (K.J.).	Approved substitute for P.S. in bombs, February, 1917 ; in shell, April, 1917.
P.G.	P.S. and C.G.	Sanctioned as alternative to N.C., June, 1917.
K.J.	Stannic chloride ..	First used in N.C. ; approved in hand grenades, June, 1917.
A.K.	Hydrocyanic acid (A.C.) and KSK.	Restricted approval for 4·5 in. C.I.Mk.x shell, October, 1917.
H.S. (Mustard gas) later B.B.	Dichlorethyl sulphide	Demanded, August, 1917 ; first issued, August, 1918.
T.D. / D.A. / D.M. }	Arsenic compounds ..	Experimental manufacture only at the conclusion of the war.

APPENDIX II.

(CHAPTER I, p. 10.)

Table showing the Main Programmes of Weekly Requirements for Chemical Projectiles, 1916–1918.[1]

Type of Projectile.	Number required Weekly.					
	Aug. 1916	Mar. 1917	June 1917	Nov. 1917	April 1918	Aug. 1918[2]
Shell.						
4·5-in. ..	23,000	34,250	34,000	34,000	34,000	50,000
4·7-in. ..	2,000	—	—	—	—	—
60-pdr. ..	10,000	11,250	5,000	1,000	1,000	30,000
6-in.	—	—	13,500	51,000	51,000	87,000
18-pdr. ..	—	—	—	—	50,000	150,000
8-in.	—	—	—	—	—	6,500
9·2-in. ..	—	—	—	—	—	8,000
Total shell ..	35,000	45,500	52,500	86,000	136,000	331,500
Trench Mortar Bombs.						
4-in. (Stokes) ..	15,000	30,000	22,500	5,000	—	1,500
3-in. (Stokes) ..	—	—	—	—	—	1,000
6-in. (Newton)	—	—	—	—	—	2,000
Projector Drums	—	3,000	4,000	4,000	4,000	4,500
Tonnage of Gas[3]	112	228	240	328	350	795[4]

[1] HIST. REC./H./1650/10, p. 99.

[2] The programme for 1919 (M.C. 1049).

[3] This quantity excludes the chlorine and C.G. charged into cylinders. The requirements for these were received in the form of "spot" demands until August, 1918, when 2,500 cylinders containing about 36 tons weekly were required for the 1919 programme (M.C. 1049).

[4] Exclusive of the requirements of arsenic compounds which were fixed at 65 tons weekly in July, 1918 (D.M.R.S. 296A.1).

APPENDIX III

(CHAPTER II.)

Advisory Committees on Chemical Warfare.

1. *Chemical Sub-Committee of the Royal Society War Committee.* (Appointed 12 November, 1914.)—Sir William Ramsey (Chairman); Professor H. B. Baker; Dr. (afterwards Sir) G. T. Beilby; Professor W. H. Perkin; Sir Edward Thorpe; Professor (later Lt.-Col.) A. W. Crossley (Secretary).

2. *Sectional Committee of the Royal Society dealing with Chemical Questions.* (Appointed 17 June, 1915.)—Professor R. Meldola (Chairman); Professor H. B. Baker; Dr. H. H. Dale; Dr. H. J. H. Fenton; Dr. M. O. Forster; Professor P. F. Frankland; Rear-Admiral S. R. Freemantle; Brig.-General L. C. Jackson; Professor W. H. Perkin; Dr. J. C. Philip; Sir William Ramsey; Professor A. Smithells; Professor J. F. Thorpe; Professor A. W. Crossley (Secretary).

3. *The Physiology (War) Committee of the Royal Society.* (Appointed 17 June, 1915).—Professor E. H. Starling (Chairman); Professor W. M. Bayliss; Professor A. R. Cushny; Dr. J. S. Haldane; Professor L. Hill; Dr. F. G. Hopkins; Representatives of Army Medical Services, Naval Medical Service, and Medical Research Committee (National Insurance Act); Dr. (afterwards Sir) W. M. Fletcher (Secretary).

4. *The Scientific Advisory Committee of the Trench Warfare Department.* (First meeting 28 June, 1915.)—Mr. (afterwards Sir) Alexander Roger (Chairman); Dr. (afterwards Sir) Richard Glazebrook, F.R.S., and Professor B., Hopkinson, F.R.S. (physical and chemical questions); Sir Boverton Redwood, Bart. (petroleum and allied questions); Mr. W. B. Hardy (physiological questions); Professor H. B. Baker, F.R.S., Dr. (afterwards Sir) George Beilby, F.R.S., Sir Boverton Redwood, Bart., and Professor J. F. Thorpe, F.R.S. (general chemical questions); Professor A. W. Crossley, F.R.S. (Secretary).

5. *The Anti-Gas Supply Committee.* (Appointed July, 1915.)—Colonel (afterwards General Sir) W. H. Horrocks (President); Lt.-Col. Starling and Major Harrison (Anti-Gas Department); Lt.-Col. Hain, Captain Lash, and Captain Seymour (Ordnance Department); Mr. Sloane and Mr. Osborne[1] (Contracts Department); Mr. G. W. Lucas, Mr. (afterwards Sir) H. Spicer, and Mr. Dykes Spicer (Contractors).

6. *Commercial Advisory Committee of the Trench Warfare Department.* (First meeting 6 August, 1915.)—Mr. (afterwards Sir) Alexander Roger (Chairman); Dr. Clayton (United Alkali Co.); Mr. H. G. Glendenning (Messrs. Brunner, Mond & Co.); Mr. R. G. Perry (Messrs. Chance & Hunt); Mr. A. T. Smith (Castner Kellner); Professor A. W. Crossley, F.R.S. (Secretary).

7. *Trench Warfare Advisory Panel to the Controller of Trench Warfare Research.* (Appointed 2 February, 1916.)—The members of the Chemical Advisory Committee[2] and Mr. (afterwards Sir) Richard Threlfall (chemistry); Mr. W. B. Hardy (physiology); Dr. (afterwards Sir) Richard Glazebrook, F.R.S., and Professor Boys (physics); Mr. Dugald Clerk (engineering); Major-General Sir D. O'Callaghan and Lt.-Col. J. Matheson (military matters).

8. *Chemical Advisory Committee.* (Constituted 2 February 1916.)—Brig.-Gen. (afterwards Sir) Louis C. Jackson (Chairman); Professor H. B. Baker, F.R.S.;

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[1] Secretary.
[2] See below, number 8.

Mr. Joseph Barcroft, F.R.S. (March, 1917); Dr. (afterwards Sir) George Beilby, F.R.S.; Professor (afterwards Sir) John Cadman (March, 1916); Lt.-Col. J. C. Matheson (A.9, War Office); Sir Boverton Redwood, Bart.; Dr. Alexander Scott (January, 1917); Professor J. F. Thorpe, F.R.S.; Professor (afterwards Sir) Richard Threlfall (December, 1916); Lt.-Col. H. E. Winsloe, D.S.O. (A.9, War Office 1917); Secretaries: Professor A. W. Crossley, F.R.S. (February, 1916); Dr. C. R. Young (June, 1916).

Associate Members.—Major R. M. Rendel, R.F.A.; Captain F. V. Lister; Captain G. H. Wicks.

Advisory Panel (September, 1917).—Professor H. C. H. Carpenter, M.A., Ph.D.; Mr. D. L. Chapman, M.A., F.R.S.; Dr. M. O. Forster, D.Sc., Ph.D., F.R.S.; Professor H. G. Greenish, F.I.C., F.L.C.; Professor J. C. Irvine, D.Sc., Ph.D.; Professor A. Mackenzie, M.A., D.Sc., Ph.D., F.R.S.; Professor G. T. Morgan, D.Sc., F.R.S.; Professor K. J. P. Orton, M.A., Ph.D.; Professor J. C. Philip, M.A., D.Sc., Ph.D.; Professor R. Robinson, D.Sc.; Professor F. Soddy, M.A., F.R.S.; Professor (afterwards Sir) James Walker, D.Sc., LL.D., F.R.S.

9. *Trench Warfare Supply Department Chemical Supplies Committee.* (First meeting 13 April, 1917.)—Sir Alexander Roger (Chairman); Mr. E. V. Haigh (Vice-Chairman); Professor (afterwards Sir) John Cadman (Liaison with Chemical Advisory Committee); Captain F. W. Bain and Captain H. Moreland (Supply); Dr. Alexander Scott, F.R.S.; Professor J. F. Thorpe, F.R.S.; Professor (afterwards Sir) Richard Threlfall; Lt.-Col. H. E. Winsloe, D.S.O. (A.9, War Office); Dr. C. R. Young; Miss F. M. G. Micklethwaite (Secretary).

10. *The Chemical Warfare Committee.* (Appointed November, 1917.)—Major-General H. F. Thuillier, C.B., C.M.G. (President); Professor H. B. Baker, C.B.E., F.R.S.; Mr. J. Barcroft, F.R.S.; Sir George Beilby, LL.D., F.R.S.; Lt.-Col. A. W. Crossley, C.M.G., LL.D., F.R.S.; Professor A. R. Cushny, LL.D., F.R.S.; Professor F. G. Donnan, F.R.S.; Professor P. F. Frankland, LL.D., F.R.S.; Mr. E. V. Haigh; Lt.-Col. E. F. Harrison, C.M.G.; Professor Leonard Hill, F.R.S.; Professor (afterwards Sir) William J. Pope, F.R.S.; Mr. K. B. Quinan; Dr. Alexander Scott, F.R.S.; Professor J. F. Thorpe, C.B.E., F.R.S.; Sir Richard Threlfall, K.B.E., F.R.S.; Lt.-Col. H. E. Winsloe, D.S.O., R.E.; Dr. C. R. Young (Secretary).

Ex-Officio Additional Members.—Commandant Overseas Artillery School, viz.:—Brig.-General S. F. Metcalf, D.S.O., R.A. Chemical Adviser, Home Forces, viz.:—Lt.-Col. A. Smithells, F.R.S. Representatives of Gas Services, France, viz.:—Brig.-General C. H. Foulkes, D.S.O., R.E.; Lt.-Col. W. Watson, C.M.G., F.R.S.; Lt.-Col. H. Hartley, M.C.; Major H. McCombie, M.C.; Major Monier-Williams, M.C.; Major L. J. Barley, D.S.O.; Major A. J. Allmand, M.C.; Major B. Lambert, R.E.; Major Hodgkins and Captain C. G. Douglas, M.C., R.A.M.C. Physiological Experts at W.D. Experimental Ground, Porton, viz.:—Captain A. E. Boycott, R.A.M.C., F.R.S., and Captain R. A. Peters, M.C., R.A.M.C. Technical Research and Design Sections, viz.:—Captain F. V. Lister and Captain G. H. Wicks. Representatives of Supply Departments—Chemical Fillings, viz.:—Captain H. Moreland. Stokes Gun, &c., viz.:—Mr. G. Leevers. Controller of Gun Ammunition Manufacture, viz.:—Mr. C. H. Stevens. Artillery Experimental Officer, W.D. Experimental Ground, Porton, viz.:—Major R. M. Rendel, R.F.A. Experimental Officer, W.D. Experimental Ground, Porton, viz.:—Major F. G. C. Walker, R.E. Representative of A.9, War Office, viz.:—Major L. C. Edwards, R.A.

Associate Members.—Brig.-General L. C. Jackson, C.B., C.M.G.; Professor J. Cadman, C.M.G.; Professor H. C. H. Carpenter, M.A., Ph.D.; Mr. D. L. Chapman, F.R.S.; Dr. M. O. Forster, F.R.S.; Professor H. G. Greenish, F.I.C., F.L.S.; Professor J. C. Irvine, D.Sc., Ph.D.; Professor A. McKenzie, F.R.S.; Professor G. T. Morgan, F.R.S.; Professor K. J. P. Orton, M.A., Ph.D.; Professor J. C. Philip, D.Sc., Ph.D.; Sir Boverton Redwood, Bart.; Professor R. Robinson, D.Sc.; Dr. N. V. Sidgwick, M.A.; Professor F. Soddy, F.R.S.; Professor J. Walker, F.R.S.; the members of the Physiological War Committee of the Royal Society.[1]

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[1] See above, number 3.

APPENDIX IV.

(CHAPTER III, p. 26.)

List of Plant provided for Chemical Supplies previous to April, 1918.[1]

(a) MANUFACTURE AND CHARGING.

1. *Castner Kellner Company.*—Chlorine liquefying (150), cylinder-charging (3,000), metallic sodium (20), chloracetic acid (20), stannic chloride (25), P.S. (10). electrolytic chlorine and liquefaction (800),[2] P.S. shell-charging and H.S. experimental plants.

2. *United Alkali Company.*—(*a*) *Gateshead*—Electrolytic chlorine (70), chlorine liquefying (50), phosgene (10), arsenious chloride (12), C.B.R. mixing and shell-charging (15,000), cylinder-charging (500). (*b*) *Widnes*—Electrolytic chlorine (30), phosgene (20), arsenious chloride (24), glacial acetic acid (38), chloracetic acid (8), shell-charging (10,000), H_2S. (20), green star charging (600), electrolytic chlorine and liquefaction (500),[2] thionyl chloride (120), sodium sulphide (120), cylinder store. (*c*) *St. Helens*—Electrolytic chlorine (30).

3. *Electro-Bleach and Bye-Products Company.*—Electrolytic chlorine (30), chlorine liquefying (50), phosgene (15), C.B.R. mixing and shell-charging (15,000).

4. *Chance & Hunt, Ltd.*—H_2S. (20), green star mixing and charging.

5. *Ardol, Ltd.*—Phosgene (20), C.B.R. mixing and shell-charging.

6. *Albright & Wilson, Ltd.*—(*a*) *Oldbury*—Phosphorus (10), shell, bomb, and grenade charging, carbon tetrachloride (20), carbon bisulphide (30), H.S. experimental. (*b*) *Wolverhampton*—Phosphorus (56).

7. *Henry Ellison & Company.*—Chloropicrin (60), N.C. and P.G. mixing, shell-charging (22,000).

8. *Sneyd Bycars, Ltd.*—Chloropicrin (60), N.C. mixing, shell and bomb charging (20,000).

9. *Cassel Cyanide Company.*—S.K. (30), sodium cyanide (40).

10. *Whiffen & Sons.*—Sodium iodide (30).

11. *Gas Light & Coke Company.*—V.N. (20), A.K. mixing, shell and bomb charging (20,000).

12. *West Riding Chemical Company.*—Thiodiglycol (10), T.D. (10).

13. *South Metropolitan Gas Company, Rainham.*—T.D. (10).

14. *Boots, Ltd.*—T.D. (experimental).

15. *Nobel's Explosives Company.*[3]—H.S. reaction (85), charging, filling, and assembling (Chittening).

16. *Graesser & Company, Ruabon.*—T.D. (10).

17. *Admiralty Factory, Stratford.*—J.L. and V.N. (40), shell and bomb charging (20,000).

18. *Usine de Laire, Calais.*—[Phosgene (60)], cylinder-charging (2,000), drum-charging (4,000), bomb-charging (10,000).

19. *Walthamstow National Filling Factory.*—Charging S.K. into shell, bombs and grenades (10,000).

20. *Bucknall Cylinder Depôt.*—Evacuating, cleaning, testing, and repairing cylinders returned from the front.

21. *Hammersmith Distillery.*—Bomb and grenade charging and filling, phosphorus (10,000).

(b) FILLING AND ASSEMBLING PLANT.

22. *National (T.W.) Factory, Watford, No. 1.*—Filling and assembling charged bombs (25,000).

23. *National Factory, Greenford.*—Filling and assembling charged shell (75,000).

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[1] The figures denote weekly capacity in tons made or containers charged.
[2] In terms of tons of bleach.
[3] In course of construction.

APPENDIX V.

(CHAPTER III, p. 31.)

Statistical Summary of Output, 1915–1918.

The following table shows the output of the principal chemicals which were manufactured for war purposes, and for which new plants were provided or existing ones extended.

Chemicals used for charging and as intermediates.	Output (Tons).				
	1915	1916	1917	1918 to November.	Total.
Liquid chlorine ..	878	4,856	7,451	7,637	20,822
Chemicals for charging					
S.K.	—*	239	885	666	1,790
H_2S.	—	190	—	—	190
C.G.	—	1,793	3,438	2,268	7,499†
B.R.	—	247	527	96	870
J.B.R.	—*	—	48	—	48
V.N.	—	—	363	—	363
P.S.	—	778	2,506	4,682	7,966
K.J.	—	—	447	1,424	1,871
H.S.	—	—	—	514	514
T.D., D.A., D.M. ..	—	—	—	96	96
Total ..	—	3,247	8,214	9,746	21,207
Intermediates.					
Bleaching powder ..	—	4,579	17,297	24,998	46,874
Sodium iodide ..	—	139	516	385	1,040
Chloracetic acid ..	—	161	598	452	1,211
Sulphur chlorides ..	—	—	—	1,265	1,265
Total ..	—	4,879	18,411	27,100	50,390
Grand Total	878	12,982	34,076	44,483	92,419

* No figures are available for small quantities of S.K. manufactured for use in grenades during 1915, nor for J.L. made at the Admiralty factory at Stratford.

† Of this total of 7,499 tons France provided 6,137 tons.

Note.—These figures do not include quantities purchased in America shortly before the Armistice, *i.e.*, 500 tons of chemicals and 2,400 tons of gas.

APPENDIX VI.

(CHAPTER III, p. 32.)

Table showing the Consumption of Materials in producing Offensive Substances.

Product.	Where made.	Name of material.	Chemicals used per ton of product. Theory usage.	Chemicals used per ton of product. Practice usage.
N.C.	Wakefield and Burslem.	K.J.	0·20	0·20
		P.S.	0·80	0·80
K.J.	Runcorn ..	Tin	0·46	0·46
		Chlorine	0·54	0·54
P.S.	Wakefield and Burslem.	Bleach	4·52	5·60
		Picric acid ..	0·464	0·70
N.C. (raw materials)	.. .. ..	Tin	—	0·09
		Chlorine	—	0·11
		Bleach	—	4·48
		Picric acid ..	—	0·56
S.K.	Glasgow	K.S.K.	0·80	0·72
		Alcohol (92%) ..	0·20	0·28
K.S.K.	Glasgow	Chloracetic ester	0·57	0·67
		Sodium iodide ..	0·70	0·70
Chloracetic ester	Glasgow	Chloracetic acid..	0·77	1·16
		Alcohol (92%) ..	0·38	1·00
		Sulphuric acid (100%).	—	0·37
Chloracetic acid ..	Runcorn and Widnes.	Glacial acetic acid	0·64	1·01
		Chlorine	0·75	1·35
S.K. (raw materials)	.. .. ..	Alcohol (92%) ..	—	0·76
		Sodium iodide ..	—	0·51
		Sulphuric acid (100%).	—	0·18
		Glacial acetic acid	—	0·56
		Chlorine	—	0·76
C.G.	Gateshead, Widnes and Middlewich.	Carbon monoxide	0·28	—
		Chlorine	0·72	1·15
H.S. (sulphur in solution before dilution).	Manchester and Avonmouth.	Alcohol (92%) ..	0·48	1·00
		Sulphur chloride	0·71	0·75
Sulphur chloride.	Runcorn and Widnes	Sulphur	0·474	0·48
		Chlorine	0·526	0·50
H.S. (as above) (raw materials).	.. .. ..	Alcohol (92%) ..	—	1·00
		Sulphur	—	0·36
		Chlorine	—	0·45

APPENDIX VII.

(CHAPTER IV, p. 39.)

Order controlling Chlorine and Chlorine Compounds.

6th September, 1918.

The Minister of Munitions, in exercise of the powers conferred upon him by the Defence of the Realm Regulations, and of all other powers enabling him, hereby orders as follows :—

1. For all purposes of this Order, " chlorine " shall mean elementary chlorine, either in gaseous or in liquid form, and " chlorine compound " shall mean and include bleaching powder, sodium hypochlorite, all descriptions of chlorine bleach liquor, and all other compounds of or products containing chlorine which are commonly manufactured direct from chlorine, whether in gaseous or in liquid form. And for the purposes of Clauses 2, 4 and 5 of this Order, the weight of any chlorine compound shall be deemed to be the weight of the chlorine contained in the same.

2. As on and from the 16th September, 1918, until further notice, no person shall produce or manufacture any chlorine or chlorine compounds in quantities exceeding in the aggregate one ton during any one calendar month except under a licence issued by or under the authority of the Minister of Munitions and in accordance with the terms and conditions of such licence as to the quantities to be manufactured or otherwise.

3. As from the date of this Order all persons producing or manufacturing chlorine or any chlorine compound, or engaged in any manufacture, trade or business in which chlorine or any chlorine compound is used, shall carry out and comply with all instructions and directions which may be given by or on behalf of the Minister of Munitions with a view to avoiding loss or waste of chlorine.

4. As on and from the 16th September, 1918, no person producing or manufacturing chlorine or any chlorine compound shall, except under and in accordance with the terms and conditions of a licence issued by or under the authority of the Minister of Munitions, use more than one ton in all of such chlorine or any chlorine compounds during any one calendar month for the purposes of all other manufactures, trades and businesses carried on by him.

5. As on and from the 16th September, 1918, no person shall supply chlorine or any chlorine compound to any person (whether in pursuance of a contract existing at the date of this Order or otherwise), except under and in accordance with the terms and conditions of a licence issued by or under the authority of the Minister of Munitions. Provided that no licence shall be required by any person to supply not more than 56 lb. of chlorine or chlorine compounds to any one person during any one calendar month.

6. As on and from the day following the date of this Order, no person shall sell or purchase or offer to sell or purchase any liquid chlorine or bleaching powder at a price exceeding the maximum price specified for the same in the schedule hereto. Provided that such maximum prices shall not apply to—(*a*) any sale of liquid chlorine or bleaching powder for export from the United Kingdom to any country other than the Channel Islands or the Isle of Man ; nor (*b*) any sale of less than 56 lb. of liquid chlorine or less than one ton of bleaching powder.

7. All persons engaged in producing, manufacturing, selling, distributing or storing chlorine or any chlorine compound, or in any manufacture, trade or

business in which chlorine or any chlorine compound is used, shall make such returns with regard to their businesses, and shall verify the same in such manner (including production of their books to any accredited representative of the Minister of Munitions being a chartered or incorporated accountant) as shall from time to time be required by or under the authority of the Minister of Munitions. And in particular all such persons shall, within fourteen days from the 1st October, 1918, make to the Minister of Munitions returns of all stocks of chlorine and chlorine compounds in their possession or under their control on that date, such returns to be sent to the Department of Explosives Supply, Storey's Gate, Westminster, S.W.1, and to be verified and authenticated by the signature of the person making the same, or, where such person is a firm or company, of a partner, director or other responsible officer. Provided that no return shall be required from any person whose stock of chlorine and chlorine compounds on the 1st October, 1918, does not exceed in the aggregate 1,000 lb.

8. This Order may be cited as the Chlorine and Chlorine Compounds Order, 1918.

Note.—All applications in reference to this Order, including applications for licences, should be addressed to the Department of Explosives Supply, Storey's Gate, Westminster, S.W.1, and marked " Chlorine control."

SCHEDULE.

Maximum Prices.

Liquid Chlorine	6d. per lb.
Bleaching Powder	£15 per ton.

The above maximum prices are net cash prices for liquid chlorine and bleaching powder delivered free on rail or into cart or vessel at maker's works, and include the cost of filling into packages (cylinders and casks), but not the cost of the packages themselves. The packages, if supplied by the maker or vendor, may be charged for in addition at not exceeding current market prices, subject to refund in full on return of the same, carriage paid and in good condition, to the maker's works, except that a reasonable hire charge may be made for packages returned after the expiration of any reasonable period stipulated for the return of the same.

Where credit is given to the purchaser a reasonable extra charge may be made, provided that the discount allowed for net cash is quoted on the invoice or in the contract for sale, and is such as to bring the net cash price within the maximum authorised.

Where delivery is made elsewhere than at maker's works all costs of transport from maker's works to place of delivery may be charged in addition, any cartage or haulage to be charged at not exceeding local rates.

APPENDIX VIII.

(CHAPTER IV, p. 55.)

List of Plant installed for Charging Chemical Projectiles.

Factory.	Projectiles.	Material charged.
(Trench Warfare) National Factory, Walthamstow.[1]	Shell, 4·5-in., 4·7-in., 60-pdr., 6-in.	S.K., P.S.
	4-in. Stokes bombs ..	S.K., P.S.
	Livens drums	N.C.
	Grenades	S.K., Hillite, K.J.
United Alkali Company (Gateshead).	Shell, 4·5-in., 4·7-in., 60-pdr., 6-in.	C.B.R., C.G.
United Alkali Company (Widnes).	Cylinders	White Star.
	Shell, 6-in., 8-in., 9·2-in...	C.G.
Electro - Bleach Company (Middlewich) (later H.M. Factory, Middlewich).	Shell, 4·5-in., 4·7-in., 60-pdr.	C.B.R., C.G.
	Cylinders	White Star.
Ardol, Ltd., Selby (later H.M. Factory, Selby).	3-in. Russian shell ..	C.B.R.
Admiralty Factory, Stratford	Shell, 4·5-in., 60-pdr. ..	J.L., J.B.R., V.N.
Usine de Laire, Calais ..	4-in. Stokes bombs ..	C.G.
	Livens drums	C.G.
	Cylinders	White Star.
West Riding Chemical Company (Wakefield).	Shell, 4·5-in., 60-pdr., 6-in.	P.S., N.C.
Sneyd Bycars Company (Burslem).	4-in. Stokes bombs ..	P.S., N.C.
National Filling Factory, Chittening.	Shell, 6-in.	H.S.
National Filling Factory, Banbury.	Shell, 4·5-in., 18-pdr. ..	H.S.
National Filling Factory, Hereford.	Shell, 4·5-in., 18-pdr. ..	H.S.

[1] The evacuation of the P.S. from 4·7-in. shell and the S.K. from 4-in. Stokes bombs was also carried out as well as the dis-assembling of the bursting charges from 4-in. P.S. bombs.

APPENDIX IX.

(CHAPTER IV, p. 57.)

List of Factories engaged in the Filling and Assembling of Chemical Ammunition.

Factory.	Work.
(Trench Warfare) Filling Factory, Walthamstow.	Filling and assembling lachrymatory shell.
Ordnance Factory, Woolwich	Filling and assembling lethal shell (1916) and smoke shell.
(Trench Warfare) Filling Factory, Watford, No. 1.	Filling and assembling chemical bombs.
(Trench Warfare) Filling Factory, Watford, No. 2.	Filling and assembling chemical shell.
(Trench Warfare) Filling Factory, Greenford.	Filling and assembling chemical shell.
National Filling Factory, Chittening ..	Filling H.S. shell.
National Filling Factory, Banbury ..	Filling and assembling H.S., N.C., and C.G. shell (1918).
National Filling Factory, Hereford ..	Filling and assembling H.S., N.C., and C.G. shell (1918).
National Filling Factory, Hayes ..	Assembling H.S. shell (1918).
National Filling Factory, Morecambe ..	Experimental filling and assembling.

APPENDIX X.

(CHAPTER VI, p. 70.)

The Chief Anti-Gas Factories in 1918.[1]

I.—FACTORIES OPERATED BY MESSRS. JOHN BELL, HILLS & LUCAS.

(a) *Oxford Works, Tower Bridge Road, S.E.*—Assembling, packing, and despatch of new box-respirators and filled spare canisters ; testing of component parts, filled canisters, etc., and drying of connection tubes ; washing, testing, and drying of used rubber connection tubes and angle tubes for Green Walk Factory ; testing and drying new connection tubes and angle tubes for R.N.A.S. ; sterilisation of used mouth-piece liners ; impregnation of horse respirators and pigeon basket covers ; extraction of chemicals from used P.H. helmets ; preparation of liquor for recovery of glycerine ; impregnation of leather gloves with raw linseed oil ; manufacture of anti-lice compounds.

(b) *Green Walk, Alice Street, Bermondsey, S.E.*—Recovery of box respirators ; filling new box respirator canisters.

(c) *Metropolitan Works, Dockley Road, Bermondsey, S.E.*—Anti-dimming outfits (for whole anti-gas service) ; fitting brass liners to mouth-pieces of small box respirators ; assembling U.S.A. Connell type of respirators.

II.—FACTORIES OPERATED BY MESSRS. BOOTS, LTD., AT NOTTINGHAM.

(a) *Island Street.*—Manufacture of granules.

(b) *Old Paper Warehouse, Station Street.*—Filling, assembling, inspecting, packing box respirators.

(c) *Parkinson Street.*—Storage.

III.—FACTORIES OPERATED BY MESSRS. JAMES SPICER & SONS.

(a) *Red Cross Street, Southwark.*—Cutting and printing mask fabric.

(b) *Edric Hall, Borough Road.*—Fitting and inspection of masks.

(c) 97/101, *Newington Causeway.*—Doping and filling masks.

(d) 155/157, *Bermondsey Street.*—Mask recovery.

(e) 34, *Camberwell Road.*—Mask recovery.

(f) *Albion House, Borough.*—Returned stores.

(g) 49/60, *Borough Road.*—Jacket-winding and inspection.

(h) *Sumner Street, and* 26, *Great Guildford Street.*—Jacket-winding and inspection.

(i) *Crowndale Works, Charrington Street.*—Splinterless glass eye-pieces.

(j) *Greenwich Rubber Works.*—Breathing mouth-pieces.

(k) *Stanstead House, Tottenham.*—Canister filling and assembling.

(l) *Fairfax Hall, Harringay.*—Canister filling and assembling.

(m) 611, *Green Lanes, Harringay.*—Nose-clip covering and inspection.

(n) 6/10, *Lancaster Street, Birmingham.*—Anti-gas stores depôt.

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[1] D.E.S./C.W./39 and 1918.

IV.—Factories Working under the Control of Messrs. James Spicer & Sons.

(*a*) *Factories of Klinger Manufacturing Company* (14 in all, including 8 at Tottenham).—Doping, fitting, recovery, and inspection of masks; cutting masks; sewing masks; inspection and packing of goggles; burnishing, blacking, and washering eye-pieces; nose-clip washering; Admiralty anti-gas work.

(*b*) *Factories of Messrs. L. H. & T. G. Jacobs* (5 in all).—Sewing masks; nose-clip covering; sewing strips for winding.

(*c*) *Factories of Messrs. Milnes, Cartwright Reynolds* (2).—Mask sewing and inspecting sewn masks.

(*d*) *Messrs. Clayton, Beadle & Stevens.*—Rubber sponge manufacturers.

(*e*) *Messrs. Logan & Brooks.*—Cutting celluloid ovals.

(*f*) *Messrs. T. J. Wright & Sons.*—Making adhesive spools, cutting and sewing cellulose and canvas strips.

(*g*) *Messrs. Lee & Binks.*—Covering nose-clips and inspection.

(*h*) *Factories of Messrs. Finch P. Ingram* (4 in all).—Covering nose-clips and inspection.

(*j*) *Factories of Messrs. T. J. Wright, Junr., & Company, Ltd.* (2).—Cutting mask trimmings and cellulose ovals; cutting cellulose and canvas for winding.

V.—Factories directly Operated by the Anti-Gas Department.

(*a*) H.M. Granule Factory, Stamford Hill.

(*b*) H.M. "Green Band" Respirator Factory, Batavia and Holloway Mills. Holloway.

(*c*) Three inspection depôts.

(*d*) Three storage depôts.

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VOLUME XI

THE SUPPLY OF MUNITIONS

PART III

OPTICAL MUNITIONS AND GLASSWARE

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CHAPTER I.

ORGANISATION OF THE OPTICAL MUNITIONS AND GLASSWARE DEPARTMENT.

I. Origin of the Department.

When the Ministry of Munitions was created the responsibility for the supply of optical instruments was allocated to the branch dealing with the supply of guns and gun equipments. This was in continuation of the pre-war practice of the War Office. Professor Cheshire, who had an extensive knowledge of the trade and of the difficulties under which it worked—its lack of organisation and of technical equipment and the shortage of supplies of essential raw materials—joined the branch as an expert on optical questions.

It was soon evident that optical munitions could not be adequately dealt with in association with guns; the problems were distinct and peculiar, as was the trade itself. Optical munitions were, therefore, separated from the Gun Department at the beginning of July, 1915, and a new branch, C.M.6, was created under the joint control of Mr. Esslemont on the administrative side, and Professor Cheshire on the technical side, who were responsible to Mr. (now Sir) Eric Geddes. The whole trade was in a critical position. No real help had been given to the manufacturer except by indiscriminate doles, repayments of which were to be made by deductions from the price of the stores supplied, and the War Office Contracts Department was quite unable to meet the demands for optical munitions.

In view of the new gun programme, which called for a vast increase in the supply of optical and scientific instruments, the new branch took immediate steps not merely to supply the manufacturing firms with financial aid, but to assist in all directions, by supplying expert technical advice, providing trained labour, accelerating supplies of raw material and semi-manufactured parts, and instituting research centres in order to set the trade upon a sound basis.

II. Gradual Development of the Scope of the Department.

The work of this section of the Ministry, which was established to deal with a shortage of optical instruments, was in course of time greatly enlarged, and the stages by which its scope was extended may be briefly outlined here. To begin with, its responsibility for the supply of optical instruments as such led naturally to its accepting responsibility for the supply of accessories, such as luminous sights, and ultimately for the supply of other articles conventionally associated with optical

munitions in manufacture, *e.g.*, drawing instruments. Next the department took over responsibility for the supply of optical glass, which in its turn led to another great extension, since the manufacture of glass suitable for optical purposes was naturally associated with that of glass for other purposes. Hence the department became responsible for the production of scientific glassware and of other articles which had nothing to do with optical munitions. And here again one activity led to another. The supply of potash—an essential constituent of most glass—was cut off by the war, and as potash was an article of vital importance to all chemical industries (including dyes and explosives) and to agriculture, new sources of supply had to be found. By the end of the war, therefore, the department was concerned with three main activities—optical instruments, glassware of all kinds, and potash production—and these activities will be separately treated in the following chapters.

On 8 July, 1915, Mr. Geddes informed the Director of Munitions Contracts that the Optical Section under Mr. Esslemont and Mr. Cheshire was in a position to take over the supply of certain articles, assuming full responsibility for all questions relating to supply and delivery other than the formal conclusion of the contract. It was understood that the Optical Section would carry forward any negotiations in connection with the supply of these articles from the point to which they had been brought by the Contracts Department. The articles concerned were :—

Telescopic Sights.	Angle of Sight Instruments.
Dial Sights.	Mekometers.
Binoculars (all types).	Field Plotters.
Clinometers (all types).	Rangefinders (all types).
Compasses (all types).	Telemeters.
Directors (all types).	Telescopes (all types).

Optical Glass.

On 14 August, 1915, Mr. Geddes arranged with the Munitions Requirements Department that the latter department would send an exact copy of each War Office requirement in triplicate, together with the original drawings, specifications, etc., daily direct to Colonel Wedgwood. These requirements were to be numbered progressively, and Colonel Wedgwood, in acknowledging the requirement, notified Mr. Layton whether the Supply Department or the Contracts Department accepted responsibility for the article being supplied.

On the same date it was agreed that in regard to optical munitions there would be two classes of articles, List " A," which the Contracts Department would deal with and assume responsibility for, and List " B," which the Supply Department would deal with and assume responsibility for. It was arranged that articles might be changed from List " A " to List " B " as the conditions of the supply varied. When an article appeared in List " B," it was clearly understood that the Contracts Department would be relieved of all responsibility for the supply, and of all correspondence on the subject, either with the War Office or with the contractors, save purely formal administrative

acts, such as calling for tenders upon a list sent in by the Supply Department. On 2 September, 1915, detailed statements of Lists "A" and "B" were agreed upon between Colonel Wedgwood and the Director of Munitions Contracts.

This system lasted until 20 June, 1916, when it was decided that requirements would in future be sent direct from the Department of Requirements and Statistics to the various supply branches and sections concerned, the optical munitions demands being sent to C.M.W., and shortly afterwards (3 August, 1916) it was arranged that demands from the War Office, the Design Department, and the Inventions Department, and requests from any of the Allies for optical and scientific instruments, were to be forwarded by the Department of Requirements and Statistics direct to C.M.6 for action.

In the autumn of 1916, the Optical Munitions Branch became responsible for the supply of navigational instruments for the Mercantile Marine. Difficulty was being experienced in obtaining these instruments owing to the increase in the shipbuilding programme, and, in November, 1916, arrangements were made whereby the Optical Munitions Branch, exercising powers under Defence of the Realm Regulation 30A, certified orders on dealers as for war purposes after the demand had been passed by the Board of Trade or the Admiralty.[1]

In December, 1915, it was proposed that the scope of the department should be enlarged to include the supply of chemical glass, and on 14 March, 1916, the Ministry wrote to the Board of Trade[2] drawing attention to the condition of the chemical glassware industry, which supplied a considerable number of articles required in the manufacture of shell steel and other important munitions, as well as for direct use at the Ordnance Factories and elsewhere. It was pointed out that the steel industry, the Ordnance Factories and the Government Testing Departments, as well as their Metallurgical, Chemical and Medical Departments, had in the past been almost wholly dependent on German and Bohemian glass for their requirements, and that in consequence there was great difficulty in supplying their needs from British sources of production. Mr. Lloyd George, therefore, considered it highly desirable to encourage the immediate production in Great Britain of the glass required, directly and indirectly, for munition purposes, and to place the manufacturing industry in Great Britain on a firm basis for continuing to supply Government requirements after the conclusion of the war. The Minister proposed, therefore, to take such steps as were possible to foster and encourage the industry, including such financial assistance as might appear necessary to place it on a firm and permanent basis, provided the Board of Trade would welcome action of this description and would be prepared to co-operate in carrying out the proposal.

The Board of Trade replied (20 March, 1916) that they would welcome any action which the Minister of Munitions might be able to take in the direction of promoting not only the chemical glassware industry, but also the supply of glass-making pots. Shortly afterwards

[1] HIST. REC./H/1930/1. [2] C.M.W./90232.

(6 May, 1916), the Director of Army Contracts agreed to the responsibility for supply being taken over by the Minister,[1] and machinery for the supply and purchase of glassware by the branch was set up at a meeting attended by representatives of the Army Contracts Department and the Ministry of Munitions.

In order to safeguard the supplies of optical and chemical glass, the Ministry set up systems of control for the manufacture and delivery of glass, glass-house pots and raw material for glass-making. On 25 August, 1916, the Ministry stated that the most satisfactory results would be obtainable if all contracts in respect of War Office requirements for glassware were placed by the Ministry on behalf of the War Office in the same way as had been done in the case of optical munitions, and this proposal was accepted by the Army Council in September.

A system of supply for chemical and medical glassware was immediately set up in the branch on similar lines to those adopted in respect of optical munitions. At this stage it was felt that, as the Board of Trade had not really sound statistics of the output and value of this particular trade, a system of control of the manufactured products should be inaugurated. On 2 January, 1917, therefore, an Order in Council[2] was obtained, forbidding anyone to manufacture chemical or medical glass or glass tubing or rod unless the purpose for which the glass was required had been approved. In addition, manufacturers were required to render to the Director of Optical Munitions and Glassware, at regular intervals, full and accurate returns of the manufacture and output of these articles.

The research work undertaken in connection with the production of potassium compounds required for glass manufacture and other vital industries proved the necessity of the creation of a government organisation for coping with the potash situation, since potash in various forms was absolutely essential for certain important optical and chemical types of glass. It was decided to hand the work over to the Optical Munitions Department, and the Potash Production Branch was formed in June, 1917.

For this material we had before the war been dependent on Germany. Steps were taken to secure from Russia in crude form certain quantities to be refined for the glass trade, but the department considered it advisable to investigate possible British sources. As the result these sources for practical purposes were narrowed down to three :—

(1) The potash contents of the blast furnace gases produced in pig iron manufacture in the North Lincolnshire district.

(2) Alunite—a potash mineral consisting of a hydrated sulphate of potash, occurring in quantity in New South Wales, and hitherto worked for the manufacture of alum rather than as a source of simple potash compounds.

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[1] Contracts/G/3425. [2] See Appendix I.

(3) Crude Indian potash, occurring in the Punjab salt range. The chief ingredient here was rock salt, already being extracted at certain points from the deposit, and the recovery of potash salts would be a subsidiary industry to that already in operation.

A provisional grant was made by the Ministry to be expended through the Director of the Imperial Institute, South Kensington, on research work. It was desirable that knowledge of the work should be confined to the Ministry, and on grounds of general convenience it was arranged :—

(1) That the research should be regarded as a secret research, and information derived therefrom should be sent only to this branch of the Ministry, and not be published without its consent.

(2) That a progress report should be rendered not less than bi-monthly to the Optical Munitions Branch.

(3) That detailed accounts of expenditure should be kept and submitted at least once a quarter for examination, certification and payment.

(4) That the selection of the firms to conduct the necessary experimental manufacture should be in the choice of the Ministry alone.

The research was completed, and the results are shown in detail in the chapter on Potash Production.

Mr. Esslemont's very valuable work for the Ministry and for the glass industry was terminated by his death in the autumn of 1918.[1] Mr. H. A. Colefax, K.C., was then appointed Controller (October, 1918) and Mr. E. Batty became Assistant Controller.

The organisation of the department at the time of the Armistice to meet the various additions to its responsibilities is shown in the chart given in an appendix.[2]

In order to give some idea of the enormous demands made upon trades which were practically non-existent before the war, schedules of service requirements are also given in an appendix.[3] These include complete instruments only, and do not show the immense volume of demands put forward for spare parts.

III. Organisation of the Department.

After the confusion of the first few weeks, the branch was divided into the following sections :—

(1) Technical.
(2) Contracts and Works.
(3) Statistics.
(4) General,

[1] The Glass Trade recognised their obligation to Mr. Esslemont by contributing a substantial sum as provision for his widow.

[2] Appendix II.

[3] Appendix III.

Each section was practically run by a single officer with the aid of two or three typists for the whole branch. The work of the first three sections is clearly defined by their nomenclature ; and the work of the General Section consisted mainly in dealing with labour questions, placing contracts in foreign countries and supervising the supply of optical glass.

By October, 1915, it was apparent that if any real headway was to be made quickly, it was essential for a system of progress inspection to be set up. In November, 1915, therefore, an Inspection Section was inaugurated. Its special functions were to maintain deliveries on contracts, ascertain and recommend fresh sources of supply of finished instruments, manufactured or semi-manufactured parts of such instruments and raw materials therefor.

The inspectors became acquainted with labour conditions, wages, and the possibilities of dilution in instrument factories, and acted throughout as the Commercial Intelligence Section. Their work was brought to the notice of the other officers of the department by means of reports which recorded statements of output, labour questions, possibilities of further contracts, difficulties in regard to raw materials and inspection of finished products, the financial troubles of the contractors, and in general every question bearing in any way on manufacture. Copies of these reports were circulated bi-weekly through the executive officers of the department, who made marginal comments on the facts and suggestions therein contained.

The reports were filed under firms, a card index being prepared of firms, instruments and raw materials, which showed :—

(*a*) The number of employees of a firm ;
(*b*) Its equipment ;
(*c*) The actual and potential output ;
(*d*) The sub-contractors employed ;
(*e*) The sources of raw material.

The allocation of work amongst the inspectors was by geographical area in the provinces, and by type of work involved in London, so that each inspector had to maintain a general knowledge of all instruments while becoming a specialist in a few.

Later on the branch was organised in the four following sections, corresponding with the natural division of the work :—

Technical Section.—Dealing with all questions relating to experimental work and technical difficulties.

Supply Section.—Negotiating all contracts and passing recommendations for completion of contracts to the Director of Munitions Contracts.

Inspection Section.—Inspecting factories and works, both as regards progress of deliveries and fresh sources of supply.

Statistical Section.—Recording demands received, contracts placed, and deliveries made.

Towards the end of June, 1915, pending the formation of the Requirements Department of the Ministry, requirements of optical munitions were obtained by D.D.G. (C.) or his subsectional officers from the War Office officials direct. Just before the Requirements Department was formed, the Ministry had written to the War Office requesting that detailed requirements for each class of munition should be supplied month by month up to the latest date possible, and in any event up to the end of June, 1916, based upon the needs of the new armies, and that such statements should include the wastage to be made good at various dates. Unfortunately, however, this system was not followed with regard to optical and scientific instruments, and the whole policy of submitting requirements to the supply department was one of the "Mother Hubbard" type, *i.e.*, the Deputy Director of Ordnance Stores formulated a demand when his stores were at a low ebb. It was extremely difficult, therefore, to formulate a distinct plan of campaign for any long period ahead.

The peculiar position of the department, in that it had to foster three highly scientific types of manufacture, prevented it from co-ordinating its work to any great extent with that of other departments or sections of the Ministry, except as a supply department, and though it had close relations with the Labour Supply Department, the Raw Materials Branch and similar sections, this could hardly be termed co-ordination of the true commercial type.

On the other hand, when in the early days of the department's existence it was trying to establish these three industries, the placing of orders by other Government Departments direct with the trade involved it in great difficulties, and it was not until 1918 that practically all Government Departments came into line, submitting their purchasing programmes to the Optical Munitions Branch before placing contracts.

CHAPTER II.

THE OPTICAL AND SCIENTIFIC INSTRUMENT TRADE.

I. Introduction.

Optical glass is an intricate, highly refined, sensitive product made to exacting chemical formulæ and standing in a class by itself. It has about as much in common with ordinary glass as a rare precious stone has with a bead. It may be mixed, according to formulæ, with the utmost exactitude and yet the resulting glass be quite unsuited to its purpose. The treatment of the mixture of the "batch" in the furnaces is at least half the art. After it is manufactured the glass is distributed to users in roughly-moulded slabs or discs which have to be shaped and polished into curved and angular pieces. This is done in an optical glass working factory, and the specification of the required degree of curvature and angularity involves specialised optical computation of the highest mathematical order. Thus prepared it becomes capable of use in aiding human vision. Its manufacture is not part of the general industry of glass-making, and the number of factories producing it in the world in any serious quantity is probably under a dozen.

Having been worked into the forms above mentioned, usually in the form of lenses and prisms, optical glass is used (by assembling these forms in more or less complicated combinations) to form an "optical system." Such "optical systems" accurately assembled within a suitable framework designed for their protection from injury and light and to secure their accurate alignment, constitute an "optical instrument," and the assembling of the finished systems is done in an optical instrument factory. Such optical instruments, when necessary for the prosecution of war, have become known as "optical munitions."

The completed optical munition has as its purpose the aiding of human vision by apparent magnification or diminution of the object viewed. Almost invariably there are added, so as to form a component part of the munition, auxiliary mechanical and calculating devices, by the aid of which much further knowledge of the object may be acquired with speed and accuracy, *e.g.*, its distance from the point of observation, its relation to other objects within or without the field of vision, its speed of movement, and so forth.

The Optical Munitions Department during the war was at one time or another called upon to provide practically all the optical instruments known to science in August, 1914, and a multitude never dreamt of at that date. Originally established to supply the War Office only with

optical munitions in which shortage was experienced, the difficulty of procuring these highly technical supplies progressively forced on the Optical Munitions Department the responsibility for supplying such munitions to all Departments of State. Moreover, the needs of the civil community had to be met to some extent, and thus by the date of the Armistice the department was recognised, as it should have been from the beginning, as the sole source of supply.

The annual value of the total output of optical and scientific instruments, which before the war did not exceed £250,000, was raised to about £5,000,000 by the date of the Armistice. This result was achieved by modernising the industry. Before the war it paid the optical instrument firms better to act as middlemen for the Germans than to manufacture themselves, partly owing to the lack of instruction in technical optics, partly to the prior knowledge of new optical glasses by the Germans, and partly to the fact that most of the firms manufacturing these instruments were long established and very conservative.

The department supplied the firms with modern machinery, introduced modern manufacturing methods, standardised the manufacture of lens polishing and grinding machines, and also of ordinary machine tools. Moreover, the number of lens workers was increased by the establishment of a training school for women, while special factories were built for the manufacture of binoculars. Modern methods were also introduced into the Mathematical and Drawing Instrument trade. At the outbreak of the war it was a small, highly-skilled home industry, and practically only two firms manufactured on reasonable production lines. The main supply came from out-workers, who were in many cases closely in touch with the larger firms and sub-contracted to them. The trade was a highly-skilled home industry, and expansion on pre-war lines was quite impossible.

As a result of this work it became possible to manufacture for the first time in England a large number of instruments, such as panoramic dial sights, periscopes, rangefinders for aeroplanes, height finders for aeroplanes, sound ranging apparatus, travel correction apparatus, and several other instruments used in the detection, location and handling of aeroplanes. The introduction of tanks also necessitated the manufacture of periscopes of suitable type, and gun sighting telescopes.

The design of some service instruments was modified in order to simplify manufacture (*e.g.*, the large clinometer, the telemeter, gun sighting telescope), as a result of work carried out by the technical branch of the department.

Another feature of the department's activity was the extension of the use of commercial radium. To meet the large demands for luminous sights for rifles and machine guns, the department undertook the supply of radium compounds and conserved such supplies for national use.

The manufacture of small precision measuring appliances, *e.g.*, vernier callipers, micrometers, etc., was before the war a monopoly of

the United States (Messrs. Brown and Sharpe and Starrett), but owing to the large demands for Aircraft Departments the department began to organise this industry in England.

In addition, as will be seen below, the department had to control the whole of the optical instrument, navigational instrument, photographic lens and optical glass trades.[1]

II. The Agreement with Messrs. Chance Brothers.

The output of optical glass in this country before the war was limited to that produced by Messrs. Chance Brothers, Ltd., of Birmingham, who had established the industry in England in 1848. The average monthly quantity produced did not exceed 1,000 lbs., and the 1913 catalogue shows that the number of types was only 15, while no effort had been made to develop the newer types of glass which had been produced from time to time in Germany.

Ninety per cent. of the optical glass used in the manufacture of instruments in this country was imported from the Continent, of which two-thirds came from Germany. In addition to the raw glass, finished optical elements in very considerable quantities were also imported from Germany. The leading optical glass firm in France, Parra Mantois et Cie, had made a very considerable progress and had produced most of the types of glass which had been evolved in Germany. The quality of the glass was not, however, up to the Jena standard as the French had only made an effort to copy the German glass, and practically all the research work in connection with the new types had been done at Jena by Schott, a very substantial grant having been made by the German Government to assist in the development of the optical glass industry. Incidentally, it may be noted that the investigations instituted in connection with the manufacture of optical glass had far-reaching effects, since it was due to that research that the Germans were enabled to make considerable strides in the improved manufacture of glass for thermometer tubing, laboratory ware and heat resistance glass.

The commencement of the War found us with a small stock of Jena glass and the capacity to manufacture about 1,000 lbs. per month, and although it appeared possible that a limited supply could be obtained from France, it was essential that every effort should be made to increase home production. With this object in view the Ministry entered into an agreement, dated 14 January, 1916, with Messrs. Chance Brothers, by which they undertook to enlarge their premises and increase their plant in order to provide for a monthly output of 8,500 lbs. It was soon apparent, however, that this amount would not suffice for the needs of the country, and in a further agreement, dated 11 April, 1916, by which the Ministry undertook to give the company very material financial assistance in order to

[1] See Appendix I.

enable them to extend further their plant and premises, the firm covenanted to produce by October, 1916, a further 5,700 lbs. per month, making a total output of 14,200 lbs.[1] Further, the number of types were to be extended so as to satisfy the legitimate demands of the opticians.

The agreement took the form of a State and industrial partnership of limited extent made between the Ministry, the War Office, the Admiralty and the firm. Assisted by a financial grant, the firm agreed to erect plant and to produce a required output of adequate quality and variety, and to provide the necessary management and scientific staff to work the plant to the best advantage in the national interest. The company further undertook to use the plant to its full capacity until a specified reserve of material of the indicated qualities and varieties had been built up.

The plant was to become the absolute property of the firm, which was entitled to use it for private trading after the war, always provided that they maintained the specified reserve and kept the plant ready to bring output up to a specified minimum on three months' notice. The firm, moreover, had to pay to the State 5 per cent. of the receipts derived from the sale of the material produced from the plant paid for by the State, and the partnership was to remain in force for ten years from the signing of the terms of peace. If the firm failed to carry out its obligations, half the sum expended by the State was to be repaid.

An important feature of the agreement was the undertaking given in it that the Government Departments concerned would, during the continuance of the agreement and so long as the firm carried out its obligations, take reasonable measures to ensure that instruments bought by these Departments should be fitted with optical glass of exclusively British manufacture.

This undertaking did not bind the Departments to buy their glass from this particular firm, but specified that *British* glass should be used. This protection is more valuable than would at first appear, for, although in normal times, with a small standing army, the purchases of Government Departments are not very large, it is probable that all manufacturers supplying Government requirements will tend, as a matter of convenience, to use the home product for their civil trade also if British optical glasses are standardised, as the use of optical glass of varied sources of manufacture may readily involve much calculation.

For convenience in working, the administration of the agreement was placed in the hands of a departmental officer known as the "Government Representative." This officer's controlling powers were wide and covered the regulation of prices, so as to maintain them upon a fair basis as between buyer and maker. The concentration of these powers in the hands of one officer avoided a frequent source of great grievance to manufacturers working under State direction—

[1] Copies of these agreements are filed in HIST. REC./H/1930/1.

the number of departments with whom they may have to deal, each exercising an authority over some particular part of the manufacturing cycle and often quite out of touch with each other. Under this agreement, while the Government Representative could take the advice of particular expert departments before making his decision, the firm concerned had only one authority to deal with.

Building operations were much slower than had been anticipated, so that it was not until May, 1917, that the company were able to satisfy their contractual obligations. Up to this period material assistance had been received from the French glass makers, Parra Mantois, Graillot and Henne.

Although the deliveries of glass to British opticians were thus unavoidably delayed, there was no actual breakdown, and, on the whole, deliveries of British instruments were fairly well maintained. The attainment of a high standard of quality of optical glass is a slow and uncertain process, and this, together with the urgent demands for glass in large quantities, accounts for the fact that the quality of the glass produced during the early years of the War was not entirely satisfactory.

The very real menace to the optical glass supply which existed from enemy aircraft whilst the country was dependent upon one factory only for the whole of its output, induced the Ministry to seek a further source of supply. After negotiations with Messrs. Wood Brothers, of Barnsley, an agreement was entered into (5 March, 1917) by which they undertook to erect a factory at Derby for the production of optical glass. The factory was completed early in 1917, but before this a few trial melts had been made in a small temporary building. With such a specialised industry, progress was of necessity slow, more particularly as the whole of the staff had had no previous experience in connection with the manufacture of optical glass. A further agreement for an increased production of glass was made on 9 December, 1918.

By the middle of 1917, Messrs. Chance Brothers had reached the position of being able to produce a monthly quantity of between 14,000 and 15,000 lb., but up to that time, on account of the necessity of concentrating upon the supply of urgent types, they had not had an opportunity of developing the newer types of glass, such as some of the dense barium crowns and telescope flints, which were required for the production of photographic lenses.

Enquiries were also made as to the possibility of utilising for the manufacture of optical glass firms who made high-class flint and other glass for table use, lenses for ship lights and other purposes. It was found, however, that the flint glass works would require new plants, both for heating and annealing and that they would require constant scientific supervision, while optical glass could not be made as a by-product. Moreover, optical glass and flint glass could not be turned out from contiguous pots in the same furnaces or annealed in the same kilns.

III. Financial and Commercial Problems.

The industry was seriously under-capitalised. It had no Masters' Association, a negligible trade union, no trade paper, no policy for commercial or technical expansion, either in manufacturing or labour resources. There was also great difficulty in ascertaining the value of the money invested in it, for practically no " costing " by modern and accurate methods existed. It is to the credit of the industry that under these conditions the owners of the individual factories embarked their available capital resources in extensions.

It speedily became necessary to supplement these resources by loans from the State in some shape or form.

The first policy—that of advancing money to be repaid by deductions from the price of the stores supplied—was discarded because of its vitiating effect on records of true manufacturing costs. Then again, money was advanced on " short " loan but on longer loan than banks were prepared to allow. Then " grants in aid " became necessary and were authorised in various forms.

As an example of the type of aid that was rendered in the early days of the Ministry the arrangements for the extension of the premises of Messrs. E. R. Watts & Son may be summarised. This firm was one of standing and repute which had executed large contracts for the War Office and Admiralty for many years. Their capacity was already utilised to the utmost extent for Government purposes, and when, therefore, a favourable opportunity occurred of acquiring land adjoining their premises it was decided to erect an additional factory (to be completed by 31 March, 1916), in order to increase the firm's output of the following instruments which were urgently required :—

Large Clinometers,
No. 5 Directors,
Artillery Telemeters,
Mekometers.

In the case of large clinometers and artillery telemeters the number of manufacturers on whom reliance could be placed for turning out a good type of instrument was very small.

Orders were placed with the firm as under :—

	Total value.
1,000 Large Clinometers	£5,375
300 No. 5 Directors	£8,345
350 Artillery Telemeters	£9,240
700 Mekometers	£6,895

making additional contracts to the value of £29,855 as the year's output of the new factory.

To enable the firm to carry out the extension a sum of £6,000 was advanced in two instalments. This sum was to be repaid by equal quarterly instalments, dated from June 30, 1916, interest at the rate of 5 per cent. per annum being payable on the amount outstanding at any date.

A double security was offered for the loan as follows :—

(1) The firm agreed to a charge over the proposed extension and contents, the estimated cost of which was about £8,000.

(2) There would be an average of at least £5,000 worth of goods either under inspection or due for payment by the Government to the firm.

The prices arranged for the instruments represented a 10 per cent. increase over the prices which had been paid in the last contracts with the firm for similar types of instruments. The increase of 10 per cent. was regarded partly as a premium for quick delivery although a proportion was due also to the increased price of materials and labour.[1]

Apart from the lack of capital, the optical instrument trade suffered from the narrow outlook of manufacturers resulting from lack of association. In order to meet this difficulty the Department promoted the establishment of Trade Associations and arranged frequent informal conferences with the members of the industry, individually and collectively. Thus, the industry was persuaded to form an approved association of British Optical Instrument Manufacturers, an approved association of British Photographic Manufacturers, and an approved association of British X-ray Manufacturers known as the X-ray and Electro-medical Section of the British Electrical and Allied Manufacturers' Association.

Their work, though still in its early stages at the end of the War, promised well, and intelligent dealing with the common interests of the industry became increasingly the rule. Such matters as insurances in common, preparation for a foreign trade policy, advertisement in common, bulk purchase, and so forth were dealt with; and regulations affecting the trade as a whole were discussed between the department and the stronger elements of the trade with the certainty that when agreement had been reached the points agreed upon would be loyally upheld by the trade.

IV. Technical and Educational Problems.

One great problem was the need for providing greatly increased technical knowledge in the manufacture of optical glass, in the design of optical systems, and the utilisation of machinery and labour in production.

In optical glass manufacture many new formulæ had to be worked out (for the mixture of some of the more important modern German optical glasses was quite unknown) and, further, when the formulæ had been worked out, effective methods of furnacing and annealing had to be learnt. The factories had to be re-designed to embody modern furnaces and annealing apparatus, research laboratories, etc., on a

[1] For other examples of financial aid rendered to firms, see the agreements with Messrs. A. Kershaw & Son, Ltd., The Kershaw Optical Company, Ltd. and Messrs. J. Brimfield & Co., copies of which are filed in HIST.·REC./H/1930/1.

large scale, and it had to be ensured that these were effectively used by being dealt with by a scientific staff, instead of one dependent on empirical knowledge.

On the chemical side, the Ministry requested and received valuable assistance from the Institute of Chemistry and the scientific bodies represented in it, and especially from Professor Sir Herbert Jackson, F.R.S.—Chemical Adviser to the department—who acted as Chairman of its Glass Research Committee. Many new optical glass formulæ were worked out and used in manufacture. Some idea of the difficulty of devising a formula and the method of manufacture of a new type of optical glass capable of meeting the exacting requirements of the optical instrument maker may be gathered by taking an average case. The production of this glass involved, even after the chemical composition had been fixed by numerous analyses and preliminary experiments, the making of no less than 150 separate and distinct trial melts with complete measurements of the optical properties of each melt, before the formula, together with the almost equally important instructional data as to treatment, could be handed on to the manufacturer to guide him in large scale production.

At the end of three years, the output of optical glass in the United Kingdom was 60 times greater than the pre-war output. Seven varieties of optical glass could be produced here as well as in Germany, and another fourteen or fifteen varieties well enough to pass muster, except against Germany's pre-war best; though to hold a real grip on the world market in peace time, we ought to be able to do perhaps forty varieties superlatively well. We had reached the stage of meeting our own needs punctually except when an entirely new variety was called for, and in addition we were able to export enough to be of material assistance to the Allies.

Some idea of the difficulties encountered in spreading technical knowledge as to the design of optical systems may be gained by stating that the manufacture of optical munitions was spread over some 190 firms, that optical computation could be done by perhaps five persons in the country and original optical design by perhaps a dozen. Out of the total number of firms not more than seven possessed an efficient design department. When it is added that at the start not one of them was prepared to lend assistance to another it will be seen that the Ministry had practically to provide a system of education for the whole industry.

The fact that Professor Cheshire, with his unrivalled knowledge, was attached to the department as adviser on all technical matters, was of the greatest assistance. From his previous official position as Examiner of Patents he was familiar with the progress of optical design, both here and in foreign countries, extending over many years, and as a result, the confidence of the industry in the department's technical ability to deal with its difficulties was gained. None the less, it was necessary to spread technical knowledge in the factories. To secure this, an Inspection Department recruited in a special way was built up.

No one who in the past had been connected with the trade in a money-making capacity was employed as an inspector, but men of the highest technical qualifications obtainable were appointed, and firms in the trade were practically told that they must teach these men to inspect from a manufacturing standpoint. Every inspector had to sign a binding undertaking that he would not disclose any secrets that he might acquire to other than the head of the department.

The better class manufacturers realised that the effective training of the inspectors was in their own interests, and dishonest makers were early brought to book. In course of time every manufacturer willingly disclosed his difficulties and secrets to the inspectors or the head of the department, and accepted in a patriotic spirit a ruling from the department that an alleged "secret" should in the interests of the trade and of the country become common knowledge.

This arrangement in regard to technical inspection also had an important effect on easing the position between the maker and the final Service Inspection Departments. The technical side of the branch had a knowledge of the situation from every standpoint, and, owing to the service of its technical advisers in the Design and Inventions Departments, and to its close touch with manufacture, it was able to advise the Service Inspection Departments as to how far rigid tests could be met under existing manufacturing conditions.

Outside scientific assistance was used without hesitation, help being obtained from many sources, including Sheffield University, the Institute of Chemistry, King's College, the Institute of Science and Technology, the Imperial Institute, Leeds University, Sir John Cass' Institute and St. Bartholomew's Hospital. The situation was far from easy, even when the seriousness of the position was brought home to the scientific world. It was not that they were not anxious to help, but that they wanted to help in their own particular and often quite unpractical way. The department got over this difficulty by insisting that the business direction of the investigation should be done by the branch, and the scientists willingly accepted this ruling. In practice they reported to the branch and the branch made itself responsible for seeing that the knowledge derived from their work was usefully disseminated.

As the amount of the scientific assistance received grew, it became necessary to find, if possible, a common table round which the various contributors could sit and form closer acquaintance. When the permanent Department of Scientific and Industrial Research was formed, just such a table seemed to become available, and the Optical Munitions Department took advantage of the opportunity. The Advisory Council of the department was induced to set up committees and sub-committees for the consideration of problems relating to the production of optical glass and optical instruments, and the Ministry exercised considerable influence in the selection of the personnel of these committees and sub-committees, which included representative members of both fighting Services, of the

trade, of scientific and educational bodies, and of the Optical Munitions Department. The technical requirements of every branch of the industry were therefore dealt with by a group of people with first-hand experience in their own lines, and sub-committees were appointed to consider the following problems :—

(*a*) Translations of foreign works.
(*b*) Optical calculations.
(*c*) Optical properties of glass.
(*d*) Physical properties of glass.
(*e*) Raw materials for glass and glass making, and fuel economy.
(*f*) Glassware testing and standardising.
(*g*) Workshop technique.
(*h*) X-ray bulbs.
(*j*) Optical instruments.

The considered opinion of these sub-committees might be regarded as the best all-round advice available which could be obtained on a given technical subject connected with the industry, and in due course this enlivening of interest in the technique of optics bore further fruit in the establishment of a national scheme of education in technical optics, under the general supervision of the Imperial College, with Professor Cheshire as Director.

Various bodies, responsible in one degree or another for the administration of educational and research funds, contributed to the support of this scheme, which would, it was hoped, provide the higher education in optics required by technical designers of the industry.

The general direction of the scheme was entrusted to an Advisory Council (elected to serve for a period of four years), on which again representatives of the Services, the industry, the National Physical Laboratory, and of the London County Council served. It started with every support from manufacturers, who appeared to realise that a course of instruction under it would form a necessary part of the equipment of their higher grade staff in the future.

A favourable reception was given by the Services to the idea of instructors being provided under the scheme for the education of officers in the principles underlying the design of the instruments they use. Officers are highly-skilled operators of the instruments but are admittedly not trained in an adequate degree in the principles underlying their construction.

V. Introduction of Improved Machinery.

At the outset the industry showed a singular lack of comprehension of what could be done by automatic and semi-automatic machinery, and by female and unskilled labour. The ideas of the trade, with a few notable exceptions, were naturally enough those of handicraftsmen,

not manufacturers. Inspection of such machinery as existed showed it to be antiquated, and the prejudice of makers and workmen alike was in favour of maintaining a skilled man to do by hand a job which a girl could do with an automatic machine For instance, the engraving on optical munitions, which at the beginning was, with very few exceptions, done by hand, was later done by girls with an engraving machine. Again, in the early days of the department it was considered that to make a prism of good standard for binoculars required—and always would require—a skilled optical glass worker of eight or nine years' experience at least, working for four hours. Prisms were afterwards turned out by machinery, except for a final touch-up, given by hand, in well under half-an-hour.

The Ministry decided that, even at the expense of some initial delay, some of the machinery used in the industry must be renewed at once, and that for certain operations entirely new machinery must be designed. A financial grant was obtained, and the assistance of the Machine Tool Department was enlisted to set aside a man to deal, under the direction of the Optical Munitions Branch, with the question of design and building.

In order to induce manufacturers to invest in the new machinery the Ministry arranged that the machinery could either be hired, hire-purchased, or bought from the department, and a show-room for makers to examine proposed machinery in at leisure with their foremen was opened, while a discussion of possible improvements in workshop technique and machinery was a regular item on the agenda of the Association and in the interviews between contractors and the department.

The result was cumulative, and out of £267,225 worth of machinery dealt with through the department, only a very small percentage was on hire, showing that the factory owner had found that it paid to buy improved machinery.

VI. Dilution and Training Schemes.

The opposition to the employment of unskilled labour was strongest in connection with the employment of women. The industry would not have them at any price, and declared almost unanimously that if they were introduced, the wastage incurred in training them and the opposition offered by the men would so seriously hamper output that it would be suicidal for the department to insist on their introduction. The Ministry, however, was determined that women must be brought into the industry. It obtained a financial grant, and equipped one floor of the Northampton Polytechnic Institute with the latest machinery and with teachers. Ten highly educated women (the majority of them with University degrees) and ten women who were simply anxious to learn a skilled trade were trained there for four to six months, the Ministry paying for their training and maintenance. When they were ready they were offered to the trade

for a trial in the respective capacities of supervisors and operatives, the wages they were to be paid being specified. Here again the results were cumulative. The school continued, and there was a waiting list of manufacturers taking their turn for absorbing the women trained in the school as fast as they could be turned out. By the end of the war manufacturers were putting women on more and more complicated work—the difficulty being to prevent exploitation of the women—and even accepted, without protest, inspection by women inspectors trained by the branch.

VII. Manufacturing Problems and Difficulties.

LENS AND PRISM WORKING.

Until the middle of last century optical working was essentially an English industry. In the latter part of the century, however, the English ascendancy, which had till then been maintained, was undermined gradually but persistently by competitors in Germany. A contributory factor of great importance in the development was the perfection to which the production of the special glass required had been brought, with government and municipal financial assistance, at Jena.[1] As a result, before the outbreak of the war important branches of the trade were practically controlled by German manufacturers, this being largely due to the fact that they had a large number of technically trained designers and workmen, although there were individual designers and workmen in Britain who were fully equal to any in Germany.

About twelve home firms continued to hold their place in face of this competition. In some of these the work produced was of undoubted excellence; in others the work was fair. The smaller firms were gradually dying out. They were copiers and not creators, and they were insufficiently equipped with a knowledge of applied optics. Moreover, they were conservative and content to carry on their work on the old empirical lines. They were not sufficiently skilled as engineers to realise the place that machinery might take in lens production, nor did they employ engineers who knew enough about optics to enable them to design suitable machines.

A wide field in applied optics is open to the manufacturer. Microscopes are greatly used in various branches of industry and manufacturing processes; cameras are largely used for industrial, commercial and educational purposes; spectroscopes, polarimeters and saccharimeters are common instruments in scientific and technical work; sextants and theodolites are important navigational and surveying instruments; while such instruments as rangefinders, telescopes, binoculars, periscopes, optical gun-sights, gun directors, heliographs, are all essential for naval or military purposes.

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[1] An account of the developments at Jena is given in *Jena Glass and its Scientific and Industrial Applications*, by Dr. H. Hovrstadt. (Trans. Everett.)

At the date of the Armistice about fifty firms were engaged in lens and prism working, some twenty of them having been called into existence to help to meet the demands of the war. The work done by the others was considerably modified to meet the Ministry's requirements. Thus the work of Hilger, whose spectroscope prisms and plane parallel plates for scientific work were unsurpassed ; of Taylor, Taylor and Hobson, Ross and Aldis, whose photographic objectives were well known ; the work on photographic and microscope optics of Watson and Beck ; on microscope lenses by Swift, and on photographic objectives by Dallmeyer ; the theodolite optics of E. R. Watts, Ottway and Cooke, and the large astronomical telescope objective work of Grubb—nearly all of this gave place to work on optics for instruments of war-time utility.

In the majority of cases the firms engaged in optical work also did the mechanical work for and the adjusting of the instruments. Exceptions to this statement may be noted. Messrs. Hilger, Ltd., made a very few complete instruments, but might be regarded as specialists in prism work to the trade, supplying such firms as Ross, Barr and Stroud, R. & J. Beck, Ltd. Messrs. Taylor, Taylor and Hobson, Ltd., and Messrs. Aldis supplied the trade with spherical work, while Messrs. Barr and Stroud, Ltd., were under contract with the Ministry for supplies of binocular prisms to be used by other firms. Several smaller firms did optical work for instruments, the complete manufacture of which they did not undertake.

Some of the chief manufacturing problems may be noticed here. Special attention has to be paid to the moulding of optical glass into discs, etc. For the economic production of polished lenses it is not sufficient that these castings should be of approximately the correct size and thickness. They should be of such a diameter, of such a thickness, of such a curvature, and have such a surface that in polishing the lens the first rough grinding process can be entirely dispensed with. Bad moulds or careless moulding may produce discs which take almost as long to bring to the smoothing stage as if they had had to be cut out of the slab.

The chief abrasives used are diamond, emery and carborundum. Diamond is generally used in the form of diamond dust. Supplies generally consist of Brazilian or South African bort or of chippings from the purer form of diamond, which are imported in the normal way. The diamond is used for slitting glass, being forced into the edge of the slitting disc. In some cases slitting discs already armed with diamond are brought from America. The diamond is also used for "milling" glass, where a solid copper cylinder, the surface of which is charged with diamond, acts as the milling agent.

Emery, an impure form of carborundum which is an aluminium oxide found in nature, is generally used for smoothing. It can be rendered fit for re-using by washing carefully in water, and separating the coarser grains out by means of sieves under water and the finer grades by settling in water. Carborundum is used for rough grinding

and also for slitting. Sufficient supplies of these abrasives and of their artificial substitutes, alundum, crystolen, etc., were obtainable throughout the War, while rouge, which is used as the polishing medium, was obtained largely from America, though a certain amount was manufactured in this country.

Prior to the War, nearly every optical worker had a different type of machine; often it was of his own design and even of his own construction. No engineering firm of repute took up the making of high-class optical machinery as a special line. The optical manufacturer had thus to employ engineers who naturally knew nothing of what degree of accuracy was required in the machine. The result was not always satisfactory. Where the optical manufacturer had an efficient tool-room staff he could build machines to his own design, but not all were in this fortunate position. After the outbreak of War the necessity of having good optical working machines of a high degree of accuracy was seen, and several firms were induced to manufacture what might be called standard types.

The roughing machine is usually a single power-driven spindle, the tool being of such a style as may be required by the type of work to be done. For small work, foot power treadle machines may be used for roughing, smoothing and polishing, but power polishing machines with automatic arms are generally used for heavier work. These machines are multiple spindles, the number of spindles depending on the size of tool to be used, and may vary from two up to ten. In the usual type each spindle is driven from a horizontal axle by means of friction discs. The driving wheel of the spindle can be moved across the face of the friction disc, and in this way the speed of each spindle can be regulated independently of the others. The automatic arm is driven by an eccentric, which is driven from the spindle by means of a belt and pulleys, and the relative velocities of the spindle and eccentric can thus also be varied.

Different types of centring heads are in use. The simplest is a small bench lathe operated by a bow held in the worker's hand. Another consists of a hollow spindle with a mirror at its base inclined at 45 deg. to the axis of the spindle, reflecting the light through the hollow spindle head, which is knurled and can be rotated by hand.

The slitting discs used are either of mild steel, with carborundum as the abrasive, or of copper charged with diamond dust and running in paraffin. The slitting machines are fitted either with an automatic or a hand feed.

Besides these, the industry uses a limited number of modern machines, including disc-cutting or trepanning machines, automatic centring and edging machines, mechanical lens grinding machines and automatic prism grinding machines. The question of the design and construction of machines suitable for optical work has received great attention, and machine tool making firms are to some extent specialising in this work.

At the end of the War some 1,400 workers were employed at lens and prism working, of whom about 340 were women. In this work dilution was possible, and had taken place to a large extent. The distinct shortage of skilled glass-workers was recognised early in the war, and in a few cases independent attempts were made by the manufacturers themselves to cope with the situation by training unskilled workers; but many difficulties had to be overcome. As there was no apprenticeship system in general operation, there was no reserve of semi-skilled boy labour to draw from. Besides this, other trades offering more obvious inducements had already absorbed all the purely unskilled boy labour. Female labour, however, was available, and it was generally admitted that optical work such as lens and prism grinding and polishing was work for which women are physically and temperamentally well suited. There was always, however, the drawback that the immediate result of the introduction of any type of unskilled workers would be a temporary diminution in output, owing to the disorganisation of the regular routine work of the shop, the loss of skilled men's time spent in teaching these unskilled workers, the wastage of valuable materials, and the working of machines at less than their maximum capacity. This, at a time of such special pressure, was not encouraging to the smaller firms, but as a result of pressure by the department, there was at the date of the Armistice hardly any branch of the work in which women were not employed.

In addition to the skilled labour required in the workshop, the services of a skilled optical computer or designer are essential for the efficient and economical production of optical elements. Without him, the firm's work is almost sure to degenerate into copying, offering little possibility of expansion or development. He should have a sufficient knowledge of the practical side of the work to enable him to tell whether the paper lens or system he has designed can be produced in the workshop, and should be able to give sufficient information as to curves and material to enable the works' foreman to prepare tools to produce lenses of the required curvature.

The production of polished lenses and prisms has become more and more a matter of efficient machines and machine tools. There will always be a place for the highly skilled worker, but he should have at his disposal tools of a high degree of accuracy to perform automatically at least all the preliminary operations. The shanking of lenses by hand should be done away with as being wasteful both of time and material. The use of glass in the form of moulded discs or of a glass disc cutting machine obviates the necessity for shanking. The rough grinding by hand of individual lenses or prisms required in large numbers should be unknown. Automatic or mechanical grinding machines should be used, while for prism smoothing and polishing, special jigs can be adopted which make unnecessary the separate working of the individual prism, and the value of such tools has been demonstrated by firms producing the highest class of work.

For certain work, as, for example, miscroscope lenses or special steep curve telescope or photographic lenses, mechanical production

in bulk is not possible. But wherever possible the use of automatic machines must be encouraged and adopted if economical production is to be attained.

In general, instrument making firms prefer to be independent of other firms as far as possible and to make all the essential components for themselves. The result is that a large number of firms are engaged incidentally in the manufacture of optical components, many of them doing the work inefficiently. If a few firms undertook the manufacture of optical components on a large scale they would then be able to secure the services of capable designers and efficient machinery, and dissipation of energy and multiplication of tools would be avoided.

The policy of the department was to encourage specialisation by placing contracts for large quantities of prisms and lenses with special firms, and if this specialisation continues, the firms will be able to supply optical elements from stock, while, if this stock is of a sufficiently wide range and of known quality, design by instrument makers will be simplified as they will know what elements are available for their use.

The Ministry had to supplement the activities of the trade; in one case a small firm was taken over and reorganised, in another case a new factory was built. At the commencement of the War, a small firm, partnered by two brothers De Braux, was engaged in the production of small optical elements, as sub-contractors to the firms holding direct contracts. Their work was of very good quality; the orders increased considerably and the business developed to such an extent that fresh capital had to be found. A company—the Periscopic Prism Company—was formed, but, unfortunately, those who had the greatest financial interest in it were totally ignorant of the trade. The company had undertaken several direct Ministry contracts, but before very long deliveries on these contracts were being prejudicially affected by the bad financial position of the company, and by the fact that most of the time of the Works Manager was taken up on financial matters and ordinary routine duties instead of being devoted to production.

The principal output of the company was unit sights for aircraft machine guns and telescopic rifle sights and, as most of these stores were of a most urgent character, the Ministry decided to take over the works and to run it as a Government factory. The shareholders were paid out at par, and three directors were appointed from the Optical Munitions Branch to carry on the business of the company. The output from the works was very materially increased, and considerable deliveries were made on telescopic rifle sights, unit sights, variable power telescopes and high angle telescopes. The works were also reorganised to provide for a considerable output of gun-sighting telescopes for the Navy.

As a means for improving shooting, the Air Force had evolved the Hythe Gun Camera, and in connection with its manufacture a large number of lenses were required. The lenses which were used in the

Air Service at the beginning of the War were of the large aperture flat field type of 8¼ and 10½ in. focus, generally of the Tessar and Cooke varieties. All those lenses which were held in stock and which satisfied the required conditions were taken over, but the supply fell far short of the demand.

The difficulties connected with the production of these high grade lenses was due to the small number of firms in this country who were capable of manufacturing and the very limited staff at their disposal. These difficulties were complicated by the fact that the types of lenses required made the most exacting demands upon the glass makers. Prior to the War, the bulk of the glass used in such lenses had been imported from Jena, supplemented by a small quantity from France. Certain of the types of glass which were essential to production were not procurable from British sources. This particularly applies to dense barium crown and telescope flint glasses.

When the stock of Jena glass which was held by manufacturers became exhausted, the necessary supplies were obtained from France, from which country also a certain number of finished lenses were obtained, although in the early days nearly the whole of the produce of the French opticians was required for their own services.

The production of a sufficient number of lenses together with an adequate supply of glass suitable for their manufacture was a source of considerable anxiety over a long period, and when the department took over the responsibility for providing photographic lenses (January, 1917) the Minister issued an order (19 January, 1917) in which a considerable number of lenses were requisitioned and withdrawn from private and commercial use.[1] Within three weeks of this order a complete census had been obtained, and a large number—about 400—of very suitable lenses was obtained.

The heavy demands for glass used in the manufacture of other munitions of war imposed such a burden on the British glass manufacturers that they were not able to devote any time to the development of those more difficult types which were required for photographic lenses, and the Ministry in consequence continued to rely upon French imports.

In the late summer of 1917, the Air Ministry proposed to alter the type of lenses in use on account of the necessity of photography at high altitudes, and where the lens had previously been one of 10¼ in. focus this was changed to one of 20 in. focus. This change of focus with the maintenance of the same relative aperture meant an increase in the quantity of glass used in the production of each lens, as the latter type required approximately six times as much glass as the former.

It was evident that unless a supplementary source of supply was found it would be impossible to keep pace with the camera programme, which was increased by demands from the French and the Americans. The supply of glass from France threatened to fall off, owing to the shortage of coal and the desire of the French Government to ensure

[1] See Appendix I.

that a sufficient supply of French glass should be available for the use of their own opticians. Also it was evident that the policy of the French authorities in the future would be in the direction of supplying finished articles rather than the raw or partly prepared material for their production. It became necessary, therefore, to redouble the efforts to secure an increased output and the production of the more difficult types of glass from home sources.

A factory was set up for the production of lenses to meet the requirements of the Air Force, and it was hoped that it would be possible to produce in addition the glass elements of a simpler type of substituted lens which had been decided upon to amplify the supplies of the 20 in. lens. Mr. Emerson, of the Guaranteed Lens Company, who had had considerable experience in lens production, agreed to undertake the management of such a factory, which would be equipped by the department, and suitable premises were found at Brimsdown. The work of equipment went forward as rapidly as possible in difficult circumstances. An inevitable delay occurred in connection with the alteration and repair of the building and the installation of the necessary power. As soon as a few spindles were erected, and without waiting for the complete equipment of the factory, work was started and the first lenses were produced in July, 1918. About this period the factory which had been set up by the Derby Crown Glass Co., Ltd., at Derby, for the manufacture of optical glass, was in a position to render some useful assistance, and small quantities were available from this additional source. Considerable extensions had also been made at the works of Messrs. Chance Brothers, Ltd., and early in 1918 the various types of glass required for the production of this new 20 in. lens were being made in sufficient quantities to enable a fair number of lenses to be made up, although these were not sufficient to meet the demands of the Air Ministry. Several conferences were held at Paris between the British, French, and American authorities to arrange the allocation of French lenses for the use of the respective Services, and as a result the Ministry obtained an immediate delivery of about 50 lenses and a promise of a further monthly delivery of a certain percentage of the French output. In order to ease the situation, the Air Ministry agreed to adopt lenses of a less complex type, which enabled the resources of other manufacturers to be brought into use.

It is satisfactory to record that, in connection with the production of lenses of the higher type, the improvement in the quality of glass and the skill of the opticians was such that comparative tests made with Ross' "Xpres" and Taylor, Taylor and Hobson's "Aviar" demonstrated the superiority of these two lenses over the "Tessar" of German manufacture in connection with aerial photography.

PRISM BINOCULARS.

Before the outbreak of the War, only four firms in this country were engaged in the manufacture of prism binoculars. The amount of labour and of raw material required was small, and as a

consequence the trade was practically negligible. Supplies of good binoculars could readily be obtained from the Continent, and the British manufacturers were dependent on continental sources for essential parts, *e.g.*, screws, optical glass.

During the War, the firms actually engaged in the manufacture of binoculars were pressed to increase their output, and new firms were initiated into the work. In November, 1918, fifteen firms were engaged on the manufacture of complete binoculars, eight of these being engaged almost exclusively on this work Other firms assembled and adjusted binoculars, while others again made binocular parts only for the use of the trade, the total output being about 500 per cent. above the pre-war production.

In certain cases the Ministry subsidised firms so as to enable them to overcome the initial financial difficulties involved in taking up the manufacture of binoculars on a large scale. Thus, a grant of £20,000, only half of which was repayable, was made to Messrs. A. Kershaw & Sons, which was expended in building and equipping a factory to produce about 1,000 pairs of binoculars per week (15 June, 1916). The Ministry also brought into existence a new firm—that of Messrs. J. Brimfield & Co.—by equipping and fitting a factory and supplying the firm with all raw material, thus relieving them of financial responsibility, the firm carrying on the manufacture on a cost basis (28 July, 1916). A further agreement for binocular lenses was also negotiated with the Kershaw Optical Co. (16 January, 1918[1]).

All three agreements ensured supplies of binoculars during the War, and provided for a Government representative on the lines already referred to.[2] Under these agreements the firms were bound to provide and maintain a technical and commercial staff sufficient to ensure the manufacture of binoculars in the most scientific and skilful manner possible ; to train and use the service of unskilled and female labour to the utmost extent possible, consistent with accuracy and expedition in manufacture ; to employ British born subjects only ; to observe and fulfil the obligations of the fair wages clause ; to keep accurate and separate records of expenditure, and to use optical glass of British manufacture.

The raw materials used in the manufacture of binoculars consist of the following :—

Hard rolled brass sheet.	G.S. strip for washers.
Solid drawn tubing.	Ribbon steel for springs.
Brass rod.	Screws No. 10 B.A.
Aluminium bodies.	Screws No. 12 B.A.
Mandrel drawn tubing.	Screws No. 7 B.A.
Mild steel rod.	Glass (various kinds).

The aluminium bodies are protected by being covered with a coating of rubber moulded on and then vulcanised. In other cases unvulcanised sheeting is cemented to the body by gutta percha and

[1] O.M.G./B/225. [2] See p. 11.

then baked. In other cases a covering of goat's skin leather is cemented to the body. The eyecups are either turned out of the solid ebonite rod or have the rubber moulded over brass shapes and then vulcanised.

The manufacture of the mechanical parts occupies about 31 per cent. of the total time taken to make the binocular. It includes such operations as turning, drilling, milling and profiling, capstan lathe work and stamping. The most important of these is turning. The other operations can, in general, where suitable tools are provided, be performed by girls or unskilled workers.

The time occupied on the manufacture of optical elements is about 39 per cent. of the whole. It is work which, while requiring a considerable degree of care and accuracy, is well suited for women, and lends itself readily to dilution. By the end of the War women were engaged in every branch of this work and in nearly every shop doing binocular optics, and the number of them employed was rapidly increasing.

Assembling and adjusting occupies 27 per cent. of the total time, and generally requires workers of some degree of skill. In addition there are miscellaneous operations which include covering, bronzing, enamelling, engraving, and represent about 3 per cent. of the total time required to produce the instrument. These operations are readily learnt by women, and were generally performed by them by the end of the War.

The manufacture of the mechanical parts of the binocular is essentially an engineering proposition, and approached as such is carried out much more expeditiously and economically. With an efficient tool room and a well organised machine shop, each machine, with its special attachment, should be kept for one definite operation. For the longer operations two or more machines should be allocated so as to preserve a proper balance. Thus the parts would pass continuously from one machine to another, tools and machines being multiplied in the proper proportion in accordance with the output required. The mechanical operations could almost all be performed by unskilled labour, and considerable dilution is possible.

The general practice is for the adjuster to receive the binocular after it has been completely fitted, together with a complete set of optics. He then proceeds to fit the prisms and lenses and effect the adjustment of the binocular. It leaves his hands practically ready for use. In this way a moderately good worker can do ten or eleven pairs per week. To effect dilution here, under such a system, involves training an unskilled worker in the whole process of binocular adjustment, which takes some time. The other alternative, of course, is to re-organise the whole system of adjustment, to divide up the work into several operations, and have one worker do a limited amount of operations, leaving the really difficult operation for the skilled adjuster.

Thus, such operations as fitting on the prism clamp, fitting the prisms in their seatings, screwing down the prism springs, adjusting

the prisms so as to give proper alignment, mounting the eyepieces, fixing screws in diopter collar, etc., can readily be done by girls once they have been shewn what to do. With proper checking and supervision there is no reason why the quality of the work done should be lowered by the introduction of such unskilled labour.

Clinometers.

Ten different types of clinometers have been produced during the war, viz. :—

(1) Field Mark III
(2) Field Mark IV
(3) Field Mark V
(4) Indian
(5) Inspectors
(6) Large
(7) Pendent
(8) Sight
(9) B.L. 10-pr.
(10) Trench Howitzer.

Of these, the only types for which there is any peace-time demand are the Indian and the pendent clinometers.

Simplifications of design in the field clinometer have been made with the object of making the manufacture easier. The introduction of photo-etching for the graduations has diminished the work, and therefore the cost of making these instruments, and a further improvement was foreshadowed, in August, 1917, by the introduction of a new process, devised by Rheinberg & Co.

In the manufacture of large and inspectors' clinometers, the main mechanical difficulty is the production of the screw and its nut. These call for specially fine lathes and a high degree of skill on the part of the workman. A Waltham Screw Miller is used in some instances to do the roughing out of this double-threaded screw, which is finally polished in a lathe. The bearing surfaces are ground in a surface grinder as the very last operation, in order to minimise any chance of local strains being set up during assembling. The cam also, which bears the bubble, is ground in position.

The graduation of these instruments calls for special graduating apparatus. The methods adopted differ in different firms, *e.g.*, a platform pivoted at its centre may be used which moves over a divided circle. Direct readings of the inclination of this table are thus obtained. On the other hand, the graduation may be carried out with reference to a standard inspector's clinometer. Given suitable tools and jigs, apart from the fitting and assembling, the sole operation which calls for highly-skilled men is that of the construction of the screws and nuts for the large clinometers and for the inspector's clinometers.

Magnetic Compasses.

The main supplies of magnetic compasses are of three kinds :—

(1) Compass Prism, Mark VII.
(2) Compass, Plane Table.
(3) Compass, Magnetic Pocket.

The manufacture of compasses, though requiring a certain degree of nicety and delicate mechanical skill, especially in the first two compasses, is the sort of work that handy skilled men in small firms, after a little experience, do very successfully. A very large number of relatively small firms have done work of this class, but it usually took them from six to twelve months to produce compasses to pass the Woolwich tests. One of the chief difficulties was to secure brass free from iron for the manufacture of the brass cases.

The cases for the pocket compass are hunter cases, and practically only one firm in this country produces a high class article. The compasses also required pearl dials (the mother-of-pearl being imported usually from Switzerland), which are divided into degrees, and the finest quality magnet steel.

One of the requisites for this industry, which created considerable difficulty in the early months of the war, owing to lack of a high-quality home supply, was the highly-polished "jewel," carrying the compass card, into which the steel pivot works. The Ministry gave considerable attention to this matter, with the result that in November, 1918, six firms were producing a high-quality product, so that there was no need, as heretofore, to depend on Switzerland and on Germany for supplies.

These six firms only employed six men of military age, most of the work being done by women, who are quite competent, after six months' experience, to turn out satisfactory work on automatic or semi-automatic machines.

If large contracts are placed, relatively diluted labour can be employed on all these compasses. The final delicate fitting and adjusting of both Mark VII and the Plane Table Compass require skill and experience. In the pocket compass little but diluted labour is required.

DIRECTORS.

Various types of directors were made during the war. Director No. 1, Mark III, was very simple, consisting of a boxwood rule with folding vanes.

Director No. 2, Mark II (only three of which were made during the war), is a high-class measuring instrument. Director No. 3, Mark I, is not considered, as none were made during the life of the department. Director No. 4 is a very special instrument, embodying a prism erecting system in the telescope; it is, in fact, a suitable mounted prism monocular. Director No. 5 is a very important instrument, and is in effect a type of theodolite, but with a constructional difference. Instead of the accurately divided circle of the theodolite, a carefully cut worm carrying a reading drum and worm wheel are used to make the angular measurements.

The raw materials required for these directors are, as in the case of theodolites, the usual scientific instrument makers' materials, "brass and glass," and present no special features. For the No. 4

director a normal equipment of lathes, universal milling machines, and drilling machines fulfil all the needs. The optics are those of a prism binocular.

The No. 5 director involves in its construction problems very similar to those of a theodolite, and the same general machine equipment is necessary. As in the case of the theodolite a special dividing engine of high accuracy is essential, so in the case of the No. 5 director a really accurate machine for cutting the teeth on the worm wheel is all important. The ideal machine should be specially built for the work, and should produce a worm gear with an error rather less than one minute of arc all round the circle. Such a machine can cut the whole of the worm wheel teeth in ten minutes. The teeth are then in their finished state, no hobbing, grinding, or other process is attempted. This machine is of simple operation and can be run by a woman.

The most obvious firms to undertake such work as the No. 5 director were the theodolite firms, who naturally put fully skilled labour on to the job. Even when such firms were given large contracts it was some time before they could be induced by elaborate preparation of jigs, fixtures and special tools to employ relatively unskilled labour. With quantity production and special preparation the manufacture of the No. 5 director, which would ordinarily be regarded as work for fully skilled men, became a job for diluted labour.

Levels.

The standard of accuracy and of finish required in the production of the best-class levels was equal to that required in theodolite work, yet, owing to the absence of divided circles and the smaller number of parts, the field of supply was much wider than for theodolites. Any capable scientific instrument firm could, if necessary, make levels. In the case of all levels, except the small pocket level and the field service level (a wooden frame level), the essential part is a telescope system, carrying a sensitive "bubble" supported in a metal framework and working in an accurate centre.

Optical glass and the usual instrument-making alloys, in the form of castings and triblet (or mandrel) drawn tubing, are employed, and a normal machine shop equipment of good class lathes (including chasing arm and dead centre types), millers, drillers, and planers or shapers can be used.

The accurate requirements of the best-class work demand in the main skilled instrument-making labour. Dilution is difficult, owing to the great number of types and the varied sizes in each type, and also to the fact that contracts are usually small—for ten or a dozen at one time. In spite of this, as in the case of theodolites, some preliminary machining and the finishing processes should be carried out with diluted labour. Further, with good tools and skilled supervision some of the body turning and thread chasing (with chasing arm lathes) should be done by women after they have had some months' experience.

MICROSCOPES.

Before the War began the bulk of the trade in microscopes was done by the German firms of Zeiss, Leitz and Reichardt, who turned out large quantities of each of their selected patterns of uniform quality and at a cheap rate. Practically only four British firms were in competition with them.

As a result of the War and the cutting off of the German supply the Americans entered the British market, and the firms of Bausch & Lomb and the Spencer Lens Co. captured part of the trade given up by the English makers.

The actual manufacture of the stands should be regarded simply as a minor engineering problem, and if the firms could decide on a few types and go in for bulk production on repetition work lines, they might be able to hold the home market and perhaps even to do a reasonable export trade. This was recognised by the British Science Guild, and in conjunction with the manufacturers, specifications were drawn up for five types :—

(1) A cheap instrument (under £10) for the use of students.
(2) A good pathological instrument for advanced work (£15-20).
(3) An expensive instrument for research (£25-30).
(4) A petrological instrument.
(5) A metallurgical instrument.

Little need be said as to the manufacture of the lenses. The main reason for the high cost is, of course, that the curves on the various lenses are of small radii of curvature, and as a consequence can only be worked a very few on a block. Further, in the manufacture of the objectives the substance has to be paid attention to as well as the polish on the surface, on account of the fact that the lenses have to be placed so close together. Apparently the trade expects its glass-work to be sufficiently profitable to make up for the stands which, with present methods, are not remunerative.

The following quotation from the report of the British Science Guild is specially interesting :—

> " The popularity of Leitz and other continental models depends on—
>
> (*a*) The remarkably high and uniform quality of the lenses.
>
> (*b*) The fact that makers will renovate and repair lenses for an indefinite period, and will make good any deterioration due to spontaneous changes.
>
> (*c*) The uniformly good workmanship and cheap prices.
>
> " English stands in many ways are just as good value for the money as continental, but, rightly or wrongly, there has developed the impression that English lenses were not of a

uniform quality, viz., makers are credited with turning out a few first-class lenses, which are highly praised by experts; but when the student buys a lens he is often disappointed. Before the trade can be captured for British makers they must be able to turn out large numbers of cheap lenses of good quality and of good keeping properties. They can at present, if they choose, easily compete in the matter of stands.

"The mounting of the lenses is very important. They should not be capable of being easily unscrewed, the setting should be strong and accurate, and the components should be finally put together under aseptic conditions, viz., the insides of the lenses should be sterile and should be so sealed up that no fungus spores can gain admission afterwards. This should not be done by the use of beeswax, as has been done in some of Zeiss' latest binoculars, as some volatile substances sweat out of the wax and fog the lenses. Close fitting is the only means that will prove satisfactory.

"Every lens should be rigorously tested by an independent expert, and lenses as good as the German should be turned out at a profit."

For tropical use, only glasses of proved keeping qualities should be employed, and the mounting of the lenses is extremely important. Aluminium is undesirable, as it undergoes changes in hot and moist atmospheres where there is any considerable amount of salt in the air, as in Madras, Bombay, etc. Some system of standardisation of the thickness of cover glasses should be adopted, *e.g.*, the extremes between which No. 1 thickness might be permitted to vary.

All available information would seem to indicate that the day of the small maker of either stands or lenses has passed. The high standard of excellence now insisted upon, together with the low prices to which buyers of microscopes have become accustomed as a direct result of foreign competition, would seem to show that the successful manufacturers of the future must be corporations of sufficient size to make it possible for them to utilise scientific guidance to the full, and to avail themselves to the greatest possible extent of special and labour-saving machinery for their work.

Rangefinders.

Rangefinders are essentially instruments for use in warfare, and are thus in a different category from instruments such as binoculars, for which there are markets other than those created by the naval or military authorities.

The firm of Messrs. Barr & Stroud, Ltd., hold practically a monopoly in this country for the manufacture of one-man optical rangefinders. Their works were built and organised solely for the production of these instruments, and before the war they were supplying not only the British Admiralty, but also the naval and military forces

of several foreign powers. Their rangefinders were at the outbreak of the War admittedly superior to any others, including those made by the German firm of Messrs. Carl Zeiss, Jena, and during the War their output increased about fifty-fold.

The firm of Messrs. Adam Hilger, Ltd., also did a certain amount of rangefinder work, manufacturing the Marindin rangefinder, but their production had almost ceased by November, 1918.

TELEMETERS AND MEKOMETERS.

The processes involved in the manufacture of these instruments include screw-cutting, milling, drilling, fitting and framing. The telemeter is a very complicated instrument, and its utility depends upon the strict accuracy of manufacture of its component parts and the proper assembling of them. To ensure this accuracy, very well-designed and skilfully constructed tools and jigs are essential. A great improvement in output was effected by simplifying the service pattern.

The aluminium body is difficult to cast, as the uneven distribution of metal gives rise to strain in cooling, which often causes cracks in the metal. This delayed output considerably in some cases. It was also difficult to obtain supplies of small screws for the telemeter owing to the great variety (forty sizes) of each, of which only one or two are required for each instrument.

If a firm had an efficient toolmaker so that jigs and tools could be made correctly at the start, about half the labour required for producing telemeters could be unskilled, skilled labour being essential for cutting the screws and fitting and assembling.

In the case of mekometers, probably two-thirds of the labour is unskilled.

TELESCOPES, PERISCOPES, AND HYPOSCOPES.

Great difficulty was experienced in meeting the enormously increased demands which arose in consequence of the war. Increased output was obtained both by developing the sources of supply existing before the war and by bringing in firms who had not hitherto manufactured these instruments, but even in 1917 and 1918 there was still difficulty in obtaining sufficient supplies of certain telescopes, mainly of the larger types, and extensions of existing works and the introduction of new firms to the manufacture of these instruments were still proceeding.

In the case of the plane mirror periscopes, the processes are not generally such as require highly skilled labour, but periscope No. 14, which was used for artillery purposes, was an optical instrument of a high degree of perfection requiring fully skilled labour. The operations involved in the manufacture of telescopes and periscopes, as far as metal work is concerned, are principally turning and screw-cutting,

and, to a less extent, milling and drilling. Turning and screw-cutting are principally done on lathes with a chasing arm attachment similar to the German Auerbach type. Screw-cutting by this method is quicker than on an engineer's screw-cutting lathe and gives more accurate results and requires less skill than the old method of hand-chasing. The lathe, however, requires to be operated by a man or youth with a fair degree of skill. Certain small parts, such as eye-caps and various screwed rings, are made on a large fully automatic machine or a capstan lathe, but, generally speaking, the number of instruments of any particular type ordered is too small to make it possible for the manufacturer to lay down the automatic machines and jigs necessary for making full use of unskilled labour.

The output of telescopes and periscopes was limited by difficulty in obtaining optical turners. Lens working is required in all cases, and prism working is required in all the periscopes and certain of the telescopes.

The materials required are principally brass tube, solid drawn and brazed mandrel drawn, gun-metal and brass castings and small screws; also optical glass. Several telescope makers drew their own mandrel brass tubing, and in this case their raw material was sheet brass. Supplies of solid drawn tubing, sheet brass, castings and screws were, of course, affected by the general shortage of such material.

Theodolites.

Theodolites are essentially instruments of precision, and their production involves the highest grade mechanical and optical skill. In general, orders could not be placed except with old established firms of high standing and with a suitably skilled staff.

The materials used are the usual scientific instrument makers' materials, and present no special features. They include metal alloys such as brass, gun-metal, bronze, bell-metal and various aluminium alloys. Except triblet-drawn tubing for the telescopes, the above materials are usually dealt with as castings (sand). Optical glass is also, of course, required.

High grade lathes, milling, shaping and drilling machines and a normal small tool equipment represent a typical outfit. For the turning of the centres, either a high grade live centre or preferably a dead centre is used. Lathes of the chasing arm type are employed for all the screw threads except the more accurate foot screws and slow motions.

For the all-important dividing of the circles special dividing engines are required. Such machines have usually been specially constructed for the firms, under the advice of high scientific authorities at various times. The really accurate use and keeping in order of such dividing engines is a high art, and most firms (rather needlessly) surround the process with a large amount of secrecy. A first-class engine should divide a circle so that the error at no point exceeds two

seconds of arc. Though it is a point of pride with the highest class firms to do their own dividing, small firms or individuals own dividing engines of varied merit, both automatic and hand cutting, and make a speciality of circle and sextant dividing for the trade.

A Swiss firm is the only one making and cataloguing dividing engines of the highest class (which cost £300 to £400 each) as a regular part of its business, but it should be possible for the British light engineering trade to undertake this work.

The accurate fitting of the constituent moving parts of these instruments is of the highest importance. In the main, therefore, only skilled and experienced instrument makers can take up this work, especially as the number of these instruments which is being produced at any one time is small. Some of the earlier work in the castings, such as rough filing, rough turning and milling operations, using jigs for the small parts, should be possible with boy or woman labour, while such work as fitting bubbles or fixing webs and such finishing processes as spray blacking, bronzing, lacquering, etc., are suitable for diluted labour, whether male or female. Where a sufficient number of similar small parts are involved capstan work with female workers should be insisted on, though in work of this class a large amount of dilution cannot be expected.

SCREWS.

An enormous number of small screws are required in the manufacture of scientific instruments as in other munition work, and the instrument makers of this country are almost entirely dependent on six firms who specialise in screws.

Very few firms have machinery specially adapted for their production, and even where there are such machines, they are seldom sufficient to meet the requirements of the firm themselves. The reason for this appears to be that before the War screws could be easily and cheaply imported from other countries, especially from Switzerland, where the work has been specialised in the neighbourhood of Soleure. Attempts to obtain small screws (say, 10 or 12 B.A. of small length and no head, which were obtainable with difficulty in this country) were frustrated largely by the import restrictions during the War.

The machinery utilised is almost entirely automatic, two principal types being in use. The lighter type, suited to the production of the smallest type of screw, is of Swiss manufacture; the heavier type, generally used for larger and more accurate work, is of American manufacture. Such screws as are used in instruments can be turned out by either type of machine at the rate of five or six thousand per working day.

The difficulties met with during the War were largely due to the inconsiderate use by designers of instruments of any and all types of screws without reference to the standard types always stocked by

manufacturers. For example, a firm taking a contract for 120 telemeters would have to purchase forty different sizes or kinds of brass, German silver, or steel screws, whereas it would be quite feasible to restrict the range to a dozen different screws.

Very small screws, even in fair quantity, are also not easily obtainable. The machines are troublesome to set up, and the separation of the screws from the waste takes too much time in proportion to the value.

The industry, as a whole, is very largely dependent on diluted labour. Dilution is easy on account of the automatic processes used. Skilled men are, of course, required for the setting of the machines, but where large orders, involving the continual use of a machine on one size of screw, have been placed, the operation of feeding the machines is easy and unskilled, and can be done by girls; the slotting and blueing of steel screws also is easily done by female labour.

Stands for Optical and Scientific Instruments.

The following types of stands were required for war purposes:—

(*a*) Directors No. 3.
(*b*) Directors No. 4.
(*c*) Directors No. 5.
(*d*) Heliograph.
(*e*) Tripods for Levels.
(*f*) Artillery Rangefinder.
(*g*) Infantry Rangefinder.
(*h*) Telemeter.
(*i*) Field Artillery Telescope.
(*j*) Signalling Telescope.
(*k*) Stereo-Telescope.
(*l*) Variable Power No. 1.
(*m*) Variable Power No. 2.

in all, thirteen different types.

The firms engaged in this work may be divided roughly into two classes:—

(*a*) Those whose normal trade it is to make optical instruments;

(*b*) Those whose normal business is of a general manufacturing type, and who before the War would have regarded stands of the types required as outside their scope.

The introduction of this second type of firm, which freed the former type of firm for optical instrument work, led to improved methods wherever large orders were given, enabling relatively unskilled labour to be used on a commercial scale.

The stands vary greatly in complexity of design. In general, it may be said that the equipment required consists of the ordinary engineering tools, milling machines, drills and lathes. The composite

character of the stands (metal and wood) leads to a good deal of division of labour between firms—there being only a few firms who can make the complete stand throughout.

It may be estimated that of about 300 persons engaged in stand production, less than 50 are women, the rest being equally divided between skilled men and unskilled men or boys. The operations done by women vary greatly according to the labour available, but appear to consist chiefly of bench work, assembling parts, bronzing or enamelling. It is only where great care has been taken to make jigs and tools absolutely fool-proof that any great dilution with women has occurred in the machine shop—the instrument-making trade apparently fighting shy of them. If care be taken in the allocation of contracts, so that it is worth a maker's while to make such jigs and tools, and perhaps more important, if competent tool-makers could always be had, there is really no limit to such dilution.

The employment of unskilled workmen or of boys instead of women is due to the unsuitability of the smaller shops to meet the conditions required by law where women are employed, and to the fact that in many cases boy labour can be obtained more cheaply.

Radium Salts for Luminous Sights.

Considerable use has been made of radio-active substances in the preparation of luminous paint for munitions of war; for example, night marching compasses, bubbles for clinometers, gun and rifle sights, aeroplane sights, instrument dials, etc. The extraction from ore of radium, the essential constituent of such self-luminous paint, involved a complicated and tedious series of operations, and only two firms in the country were engaged in this extraction.

During the early part of the War the requirements of radium for war purposes were met to a great extent by the industry. After the formation of the Ministry, as there was a possibility of extensive buying of the radium salts by the Government tending to increase the market price, it was decided to employ Mr. F. H. Glew to act as the buyer of the raw material, the Government to purchase from him. Over £23,000 was advanced, and the purchase of these compounds in this manner resulted in a very considerable saving. The quality of the radium was checked by the National Physical Laboratory on behalf of the Ministry of Munitions, and it was insured both when stored at Mr. Glew's laboratory and at the National Physical Laboratory.

During the latter part of 1917 the demand for radium increased, and, in order that the production in this country might be maintained, the Ministry placed a contract in the United States for the supply of carnotite ore, from which the radium might be extracted. As, however, the American authorities placed an embargo on the export of carnotite, it was considered essential that steps should be taken to conserve the amount of radium obtainable for purposes essentially connected with the War.

With this object in view, the Radio-Active Substances Control Order[1] was published in August, 1918.

The substances to which the order applied were radio-active substances (including actinium, radium, uranium, thorium, and their disintegration products and compounds); luminous bodies in the preparation of which any radio-active substance is used, and those from which any radio-active substance is obtainable, except uranium nitrate. The order provided that no person should offer to purchase or purchase material to which the order applied, except under a licence issued by the department.

The procedure adopted in carrying out the order was that the purchaser was required to send to the department all orders in triplicate. If the order was approved, one of the copies was licensed under a number and date and forwarded to the seller, one returned to the purchaser, and one retained in the department for record. In addition, every dealer in radium was required to tender a return by the third day of each month showing the amount of radium bought, sold and used during the preceding month, and giving particulars of the uses to which it had been put.

Attempts were also made to open up pitch-blende mines in Cornwall, so that a supply of ore might be obtained to replace the carnotite ore from America, the export of which was prohibited. On account, however, of adverse circumstances during the War, it was not found possible to work these mines.

In order to meet the demands for radium bromide, contracts were placed with various firms in the United States of America. Special investigations to determine the rate of decay in brightness of various radio-active substances resulted in a saving of radium bromide.

Another luminous compound—phosphorescent zinc sulphide—was being successfully produced under the direction of Sir Herbert Jackson at the date of the Armistice.[2]

After the Armistice the demand for luminous paint for war purposes considerably diminished, and on 21 January, 1919, the Radio-Active Substance Control Order was suspended. As it was found impossible to cancel on favourable terms contracts which had been placed in America for radium bromide, a comparatively large quantity of this material was delivered after the demand had disappeared. Having in view the results that might arise from placing such a large quantity of radium on the market, and also the possible effect of such a course on the industry, and further, having in view the uncertainty of the supply of such material in the future and the possibility of its extended use in warfare, it was decided that the material in the possession of the Ministry should not be sold.

Since radium loses only half its energy in some 1,700 years, and its depreciation is negligible, it was decided that the material should be used for therapeutic purposes while still being held as an available reserve in case the country was again at war.

[1] See Appendix I. [2] See Gen./1912.

In order that it might be used in this manner to the best possible advantage, a committee consisting of representatives of the Royal College of Physicians, The Royal College of Surgeons, The Radium Institute, The Royal Free Cancer Hospital, and the Optical Munitions Department, was appointed to formulate and consider proposals.

The first proposal was that it should be hired on certain definite terms in small quantities to the various hospitals or other approved institutions. In order to obtain an idea as to the requirements of such institutions, thirteen London Hospitals were in the first place circularised; two of these hospitals were willing to hire one gramme on the terms stipulated; several of the other hospitals objected to the large expenditure which would be involved in hiring it at the rate of 4 per cent. on the capital value of the radium.

Representations were made by the Members of the Cancer Research Department of the Middlesex Hospital, at which, under the direction of the Medical Research Committee, careful investigation was being made of the effects upon the body of exposures to radium under various experimental conditions. The Medical Research Committee pointed out that this work was undertaken originally at the request and for the assistance of the Army Medical Department, but the Committee were of the opinion that the work would have a wider interest than that. This had proved to be the case; some extremely important results of high promise having already been gained. It was shown that the loan of about 4½ grammes of radium bromide, which was nearly nine times the amount formerly used in these experiments, would not only greatly facilitate and expedite the work, but would allow work to be done which would differ not only in degree but in kind from what had been attempted so far with smaller resources.

It was therefore decided that the whole of the radium bromide available should be handed over for an initial period of six months to the Medical Research Committee, and the necessary sanction of the Surplus Government Property Disposal Board and of the Treasury, to this proposal was obtained.

In view of the high value of radium bromide, the branch considered it desirable that as far as possible the radium should be recovered from the self-luminous paint in instruments salved or returned to store as unserviceable. Samples of luminous painted compass cards, lubber lines, rifle sights, and instrument dials, etc., were obtained and forwarded to the Government Chemist, who reported that the cost of scraping off such paint and of extracting and purifying the radium bromide would be about 5 per cent. of the value of the recovered radium.

The proposal that all parts of instruments containing radium paint and otherwise unserviceable should be sent to the Government Laboratory for the recovery of the radium, together with any paint which had been scraped off and collected from parts of instruments already scrapped or repainted or otherwise made use of was approved by the Disposal Board, and the Admiralty, the War Office and the Air Ministry were informed of this decision.

VIII. The Collection of Privately-owned Instruments.

The acute shortage of telescopes and binoculars in the autumn of 1915 made it necessary to obtain possession of the large numbers of these instruments capable of passing government tests which were in traders' hands, and in addition to prevent the sale of inferior instruments to officers of the Services. It was therefore decided to control all optical and scientific instruments which could be of service to the Admiralty and the War Office, and with the concurrence of the Admiralty and the War Office an order was issued in the "London Gazette" on 23 November, 1915,[1] circulars and forms being sent to all firms dealing with instruments affected by the order on the same day.

Arrangements were made to test the whole stock of instruments coming within the terms of the order throughout the Kingdom (with the exception of those being supplied on government contracts), and to purchase all instruments which passed the government test, returning to traders, together with a licence to sell, such instruments as failed to pass the test—rejected instruments being marked thus: It was arranged that when government requirements were met, instruments passing the test but not required by the Government would be returned to traders, marked

As it was obvious that the ordinary testing facilities would be inadequate, local examining centres were established in different parts of the country, universities, colleges and technical schools being chosen for the purpose, their function being to return to traders such instruments as were obviously unsuitable for military purposes, and to send on for final testing such instruments as were apparently suitable. Twenty-four such examining centres were established at the following points :—

London	8
Southampton	1
Cambridge	1
Bristol	1
Cardiff	1
Birmingham	1
Liverpool	1
Manchester	1
Leeds	1
Sheffield	1
Newcastle	1
Edinburgh	2
Glasgow	2
Belfast	1
Dublin	1

Technical inspectors were sent to each centre to instruct the examining staff as to the lines on which the examination should be

[1] Appendix I.

conducted.[1] These local examining centres did their work expeditiously and to the complete satisfaction of the Chief Inspector's Department at Woolwich. They began work during the last week in November, and it was found possible to close thirteen of them on 21 December, eight more on 29 December, and the remaining three on 5 January, 1916.

In order further to relieve the pressure on the Government testing departments at Woolwich, the National Physical Laboratory was made an additional final testing centre for binoculars, telescopes and prismatic compasses, the examination being carried out in accordance with instructions laid down by the Chief Inspector, Woolwich, and Inspector of Royal Engineer Stores respectively.

By the middle of January nearly all the instruments in the hands of traders throughout the country had been tested, the only instruments remaining to be tested being :—

(1) Output of manufacturers not appropriated to government contracts.

(2) Instruments imported from abroad.

(3) Instruments in the hands of pawnbrokers which became "out of time pledges."

(4) Instruments offered by private individuals.

The country was swept from end to end, and by 1 February, 1917, the following instruments had been accepted as suitable for field service :—

Prismatic Binoculars	6,318
Galilean Binoculars	13,188
Prismatic Compasses	8,402
Telescopes	2,914
Periscopes	583
Lattey Lens Sights	1,400
Other instruments	214
Total	33,019

So searching was the initial requisition that by 1 November, 1918, the figures given above had only increased to 34,742.

The arrangements made for purchasing from the public worked satisfactorily ; the traders named the price at which they were prepared to sell on the forms sent in, and in the case of instruments tested at Woolwich the government examiners suggested a price for instruments passing the test.

Traders, with certain notable exceptions, submitted willingly to the inevitable inconvenience caused them by the order, a useful

[1] Copies of the books of instructions for these examinations are filed in HIST. REC./H/1930/1.

result of which, in addition to the number of instruments acquired, was that all unsatisfactory instruments coming within the scope of the order on the market were distinguished by a mark indicating their unsuitability for military purposes.[1]

IX. Attempts to Obtain Instruments from Abroad.

In the autumn of 1915, an attempt was made to obtain optical instruments from enemy and other sources. Preliminary investigations had led to the conclusion that the only country which could supply optical instruments in bulk was Germany, and in order to obviate a breakdown in the supply of these essential instruments a representative of the Ministry of Munitions was sent out to Switzerland in August, 1915, to ascertain whether it was possible to obtain instruments from German sources. Through Swiss channels it was ascertained, from information received from Germany, that the German War Office would be disposed to let the British Government have the following binoculars :

(*a*) For infantry officers, 8,000 to 10,000 at once.

(*b*) For artillery officers, 8,000 to 10,000 at once.

(*c*) For non-commissioned officers, non-prismatic 10,000 to 12,000 at once.

For the future they were prepared to deliver, six weeks after the signing of the contract, 10,000 to 15,000 a month of (*a*) and (*b*) respectively, and they were even prepared to demobilise special workmen from the Army to enable these orders to go through quickly. As regards (*c*) they would be able only to deliver 5,000 per month commencing at about six weeks after the signing of the contract.

The German War Office were also prepared to let the British Government have a stock of 500 telescopic sights, and afterwards to deliver from 5,000 to 10,000 per month, and to provide as many range-finders as the British Government required. In order to obtain samples of the instruments, it was suggested that the British Forces might inspect the equipment of captured German officers and artillery.

It was ascertained that the compensation the Germans would require would be rubber, such compensation to be made in Switzerland on the German frontier.

Before these negotiations matured the efforts of the department and the trade concerned had resulted in the position becoming easier, and no further attempt was made to develop this precarious source of supply. There was still, however, a shortage, and it was therefore decided (in November, 1915) that Mr. R. S. Whipple, of the Cambridge Scientific Instrument Company, should go to the United

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[1] A form of the certificate used for authorising the manufacture of scientific instruments is filed in Hist. Rec./H/1930/1.

States to ascertain the possibility of obtaining optical munitions from America. He was to investigate the source of supply of the following instruments, arranged in order of urgency :—

No. 7 dial sights.
No. 5 directors.
No. 4 ,,
Telemeters.
Large clinometers.
Prismatic binoculars.
No. 4 sighting telescopes.
No. 5 ,, ,,
Signalling telescopes.

In regard to No. 7 dial sights it was found that Messrs. Goertz owned the United States patent for the invention, so that if any American manufacturer were to make the instrument he would be liable to an action for the infringement of the patent.

Inquiries were therefore made as to whether these instruments could be made in Canada, where presumably any difficulties as to patents could be overcome. It was found, however, that in Canada the price asked per instrument was something like £100, whereas the English price at the time of Mr. Whipple's visit, viz., 20 November, 1915, was only about £45. It was, therefore, decided to push forward and extend the manufacture of dial sights in England rather than purchase in Canada, and it is satisfactory to note that the output of dial sights by two British manufacturers, viz., Messrs. R. & J. Beck, Ltd., and Messrs. Ross, Ltd., kept pace with the gun programme.

In regard to prism binoculars, the only two firms to undertake manufacture in the United States were Messrs. Bausch & Lomb Optical Company and the Crown Optical Company. The former company were exceedingly difficult to deal with. The instruments were not very satisfactory, and the firm once or twice threatened to close down the contract unless the inspection was modified. The British inspection authorities, however, asserted that they were passing glasses which would have been rejected by the authorities at Woolwich in times of peace. An independent referee, therefore, tested a number of glasses which had been rejected, and this independent test showed that the binoculars were certainly not of a type that would have been accepted except under urgent need, and ultimately, owing to the poor quality of the glasses, the contract was cancelled.

The Crown Optical Company were not so difficult to deal with, but their instruments were of an equally bad nature, and their contract also had eventually to be terminated.

It was found impossible to place contracts for the other instruments; the manufacturers in the States were either not prepared to manufacture at all or their price was so high that their offers could not be entertained. It was clear, therefore, that Great Britain would have to rely almost exclusively upon her own manufacturers for meeting the demands for optical instruments; it was necessary to start from bedrock and see that necessary materials were available for manufacture.

X. Inspection Difficulties.

The magnitude of the demands for instruments for the purposes of war was so great, in comparison with the initial capacity of the trade, that firms were induced to undertake work of a type somewhat different from that to which they had been previously accustomed. Many of these firms had not before worked to such close tolerances as the drawings and specifications for approved stores prescribed ; many of them did not appreciate the need for interchangeability of parts which is a necessity in the case of certain parts of service instruments which may require replacing in the field on account of their liability to become broken or detached and lost ; many of them were not accustomed to having their products rigidly inspected and submitted to definite tests and they were not acquainted with the methods of testing.

In these circumstances, it is not surprising that the percentage of instruments rejected by inspecting authorities—such as the Director of Inspection of Optical Stores ; the Chief Inspector of Small Arms ; the Chief Inspector of Royal Engineer Stores ; the Aircraft Inspection Department ; and the National Physical Laboratory—was, in many cases high, and many complaints were received from contractors as to the methods of testing and the stringency of inspection. As these were occasionally put forward to excuse delay in delivery, complaints were investigated by the technical branch. Investigation showed that while some contractors were simply making a plea for inefficient workmanship, or for the use of defective material, others were either experiencing actual difficulties in manufacture or were handicapped by misunderstandings. In order to clear away those misunderstandings, and, as far as possible, to assist contractors to overcome inspection diffiulties which appeared from time to time to militate against production and supply, the various points and complaints were put before the Director of Inspection of Optical Stores and discussed with him. Afterwards, as a result of this discussion, contractors were circularised with regard to such subjects as the use and function of samples supplied by the inspecting officer ; the necessity for the interchangeability of certain parts ; the methods of testing, etc.

The contractors were invited to visit the inspection centre and to see the actual tests applied, and the necessity for adhering to drawings, specifications, etc., and of not embodying any alterations, or using different materials, without first obtaining sanction from the inspecting officer was also impressed upon them. They were also instructed as to the necessity for submitting a forward sample ; the necessity for a firm's standard of work to improve rather than to deteriorate, and the advisability of their referring to the inspecting officer on points about which they had any doubts.

CHAPTER III.

THE GLASS INDUSTRY.

I. Introduction.

The glass industry, although not a large one, is exceedingly complex. It embraces in its scope articles so widely differing, both as regards method of manufacture and the use to which they are put, as beer bottles and artificial eyes.

Prior to the war the glass industry was in no sense a well-established industry in Great Britain. Not more than 20 per cent. of the nation's requirements were met by British manufacturers, and certain very essential types of glassware were not made in this country, and others were made in such small quantities as to be of no importance.

The development and organisation of the industry by the Glassware Branch of the Ministry of Munitions included research work; the introduction of improved methods of manufacture, together with new types of furnaces and machinery; dealing with complicated labour problems, including restriction of output and the settlement of disputes; obtaining priority for materials and transport, both overseas and inland; the setting up of systems of costing hitherto unknown in the industry; giving financial assistance and, for the first time in the history of the industry, compiling statistics of output and generally encouraging output both as regards quantity and quality.

The effect of this organisation is revealed by the following figures, which relate to the total output of the trade for types of glass in the manufacture of which no machinery was employed and where, therefore, practically no dilution was possible.

Type of Glass.	Value of output for 4 weeks ended 26/9/18.	Increase on 4 weeks ended 21/4/17.		Output prior to the War.
	£	£	%	
Scientific Glassware.				
Furnace-made	7,413	3,400	84	Nil.
Lamp-blown	36,106	15,227	72	Practically nil.
Tubing and Rod	7,778	2,840	57	Very small.
Illuminating Glassware.				
Electric Lamp Glass ..	36,922	23,782	180	About ¼ of present output).
Miners' Lamp Glasses ..	3,088	2,618	557	Nil.

This development was effected in spite of considerable numbers of men having been called to the colours.

Even at the end of the War it had to be admitted that no section of the glass industry was efficient. In those sections where no machinery existed, particularly scientific glassware, manufacture had not yet gone beyond the experimental stage and much time, money and work would be needed to place it on a sound and permanent footing. In other sections manufacture was passing through a period of transition from hand methods to machine methods, and the department pointed out that unless some assistance was given by the State to meet the competition from countries which were in advance of this country, the industry was likely to collapse before it had had the chance to become efficient.

One of the reasons why it was quite impossible to equip all glass factories with modern plant and machinery during the War, was the fact that the manufacture of munitions required for the actual destruction of the enemy made heavy demands upon building material, labour and machinery. Some types of glass were necessary for the production of munitions of war, but others, although necessary even in war time, were not used in the manufacture of munitions, and consequently in the latter case it was difficult to effect improvements in plant and machinery. Moreover, even in the case of certain types of glass essential for the production of munitions of war, the price of the glass article was not of such importance as to warrant, for the purpose of more economical production, the use of material and labour which could be otherwise used for the manufacture of war munitions. In other words, the whole of the industry could only have been rendered really efficient at the expense of munitions work.

II. Survey of the Industry.

The 30,000 workpeople employed in the glassware trade during the war fall mainly into three groups :—

(*a*) Glassmakers ;
(*b*) Gas-producer men, founders, stokers or teazers ;
(*c*) Packers, sorters, viewers and warehousemen.

Glassmakers work together in small groups or gangs which are called " chairs " (sometimes " shops " or " holes."). The members of the chair are interdependent and the absence of one man affects the whole chair and either reduces its output greatly or prevents it from working at all, so that if one man is away it often prevents four or five men from working. This peculiar organisation of the men led to great difficulties during the war ; since the calling up for military service of a young man meant that the whole chair was broken up and two or three men were rendered idle.

Under normal conditions fully twice the number of hands given above was employed. All through the industry plant was lying idle for want of men, as the trade is not one which can be filled by the unskilled labour of women and boys at a moment's notice.

The glassworkers are strongly organised, the principal trade unions being the National Flint Glass Makers' Trade Society, the North of England Glass Bottle Makers' Trade Society, and the London Glass Blowers' Trade Society. These unions have a high degree of control over the working of the trade, and all engagements of new men, the apprenticing of boys, and other arrangements relating to the men and to methods of working have to be made with their approval. Each article has its wage-price fixed by periodical agreement between master and man, and books are issued periodically by the societies setting out the agreed prices for work and the rules governing the conditions of work.

The mixers, when the batch is mixed by hand, are required to exercise great care and a certain degree of skill in order that the constituents of the batch shall be evenly mixed. Uneven mixing produces a metal which is "cordy" or "wavy," and difficult if not impossible to work.

The teazers or stokers attend to the fires and on them depends the maintenance of a clean fire, and, therefore, of sufficient heat. The gas-producer men are responsible for charging and running the producers. Unless they do their work properly, the gas produced is poor in quality, the heat from the furnace falls off, with the result that the metal is unfit for working, too stiff or not sufficiently refined, and the whole of the glassworkers are forced to stand idle for a time, perhaps for a whole day.

After ware is made it is examined for defects, sorted into grades and packed for transit. Skill is required, of course, but it is not difficult to acquire, and it is in these occupations that the men have been replaced by older and unfit men and by women.

The hours of work are governed by the nature of the industry. The metal, once it is obtained in condition to be worked cannot be allowed to cool below a certain temperature, and in order to economise heat, working should be as continuous as possible while there is metal to be worked. Night work is thus the rule throughout the trade. Each shift extends over a period of from 10 to 12 hours and consists of from 8½ to 10½ net working hours. Work is carried on during five days of the week, and the organised workers do not, as a rule, work on Saturdays and Sundays.

In the hand-made trade, as carried on in Stourbridge and district, an antiquated system of six-hour shifts exists. The men, in two shifts, work and rest in alternate periods of six hours and work eight or nine of these six-hour "turns" each week. In the glasshouses where these conditions obtain, there is no work during the week end as it is during this time that the metal is founded, to be worked out steadily during the week. As a rule there is only one melt per pot each week, but if a large number of articles of a simple character are being made, a pot may be worked out in a shorter time and "overtakers" or extra melts are then worked.

There is no doubt whatever that this six-hour shift system is against the interests of the trade. The men do not get a proper rest

and are thus liable to slack-off, and boys decline to enter a trade where they can never get their evenings free, and where it is necessary to get up in the middle of the night to go to work. Workmen who have had experience of the nine-hour shift condemn the older system which, it seems quite certain, exists solely owing to the conservatism that characterises this branch of the trade.

The heat to which the workers are exposed and the skill required prevented the employment of women as glassworkers to a large extent, so that dilution in the main took the form of increasing the number of apprentices. Women were, however, employed as packers, sorters, and washers but many firms do not consider that they are a success as substitutes for the men. In some cases, young women are employed in the glass-house in carrying the ware from the blowers to the lehrs. This is only done in works where rigid supervision can be exercised and employers, on the whole, object strongly, in the interests of the girls themselves, to employing them for this work.

III. Glass Furnaces.

The older glass factories that have been long established are usually situated in parts of a town where the houses have been built up around them, and they are therefore somewhat cramped and lack room for expansion. In their construction they consist of a conical house surrounding the furnace, and as the cone is open at the top only, they are usually dark, gloomy places. The conical construction also restricts the room available for work round the furnace. The newer glass houses, which are usually situated away from crowded areas, both because the land is cheaper and because space for expansion is available, are usually light airy workshops, especially those employing tank furnaces, and are well ventilated, with plenty of space for working.

The furnace is the principal part of a glasshouse plant, and on its successful and economical working the success of manufacture depends. The furnaces used in this country are of two main types :—

(*a*) Pot furnaces ;
(*b*) Tank furnaces ;

and these two types can be subdivided as follows :—

Pot furnaces—
(*a*) employing skittle pots ;
(*b*) employing closed or covered pots ;
(*c*) employing open pots.

Tank furnaces—
(1) heated by a coal fire direct ;
(2) heated by producer gas ;
(3) heated by oil.

(*a*) Pot Furnaces.

The pot furnace employing skittle pots is the simplest type of furnace and is extensively used in the manufacture of small bottles in

that branch of the industry known as the "Flint bottle trade." It consists of a firebrick box, rectangular in horizontal section, about 9 ft. long by 4 ft. wide, built over an excavation or pit in which is the grate. The top is covered by a flue, while a brick arch, crossing the interior and sloping from front to back, reflects the heat down on to the pots, which stand in an inclined position. The front is loosely bricked up when the pots are placed into position, leaving openings which surround the mouths of the pots. It usually holds four or five pots and is fed by coke. The heat given by this furnace is hardly sufficient to melt "batch," so that only broken glass or cullet is melted.

The furnace most usually employed is an ancient type, or an ancient type slightly modified, employing covered pots. It consists of a circular hearth or "siege" surrounded by flues resembling pillars and an arched roof. The grate is built in an excavation below the siege, and the flames come up through a central opening in the siege and are deflected by the roof down on to the pots. The pots are placed in a circle on the siege with their mouths projecting through openings in the brickwork, which fills in the spaces or "arches" between the flues. In the simplest and oldest form, the coal is fed into the grate from the glasshouse direct through an opening which replaces one of the arches. In the improved form, the grate is fed by means of a mechanical stoking device, the Frisbie Feeder, which forces the coal into the fire from beneath so that all the smoke is consumed by passing through the hot fire.

A still more modern modification, of continental origin, which is known as the "Pitt" furnace, is in essence a producer-gas furnace, but of an elementary type, and differs only from the old furnace in the arrangement of the fire-box. The fuel is fed into the upper part of the fire-box and falls into the burning mass. Air enters the grate and, passing through the fire, is converted into a combustible gas, consisting chiefly of carbon monoxide diluted with nitrogen. Before passing through the aperture in the siege, it meets with air that has been heated by passing through passages in the sides of the fire-box and below the siege. The mixture of heated air and gas burns with a hot flame which is of special value where large masses of glass have to be melted and worked out quickly, as in the pressed-ware trade.

These are the main types of furnaces using covered pots, but furnaces heated by producer gas are also in use.

One form of producer-gas furnace consists of a long siege with rounded ends on which the pots are arranged, the whole being covered in completely by an arched roof supported on brick pillars, the spaces between which form the arches for the reception of the pots. There are two apertures in the siege, and mixed gas and air enter by one and leave by the other, the direction of the flame being reversed periodically. Both gas and air are heated by passing through a regenerator, as in the "tank furnaces" described below.

In another form of regenerative furnace the pots are arranged in a semicircular tunnel, and the flames pass in alternate directions along the tunnel. The producer is built close against the back of the furnace and the air is preheated by passing through a regenerator.

At the end of the War several recuperative furnaces were about to be built. In these, the incoming air, before mixing with the gas, is passed through fireclay tubes which are heated by the gases on their way to the chimney stack. The gases pass around the tubes, and the heat of these gases is conducted through the walls of the tube to the air in the interior.

Oil furnaces in which a heavy oil is sprayed from a burner by compressed air are in use, but not to any considerable extent.

Except for making plate glass, furnaces employing open pots are not much used. Flames from a coal fire pass over the pots on the way to the flues and the molten glass is gathered through openings in the side of the firebrick box or chamber which covers the siege on which the pots stand. Such a furnace has only one advantage over a tank furnace, in that it enables a number of different coloured metals to be worked at the same time. Also, when a pit is worked out it can be filled with metal of a different colour. In a few cases the furnace is heated by producer gas.

(*b*) Tank Furnaces.

A simple tank furnace of the type known as a "box tank" is used in Yorkshire for making small bottles ("flint" bottles). It consists of a rectangular basin covered by an arched roof and provided at the side with gathering holes and filtering holes. A fire-box is situated at each end, the grate being separated from the tank by a low wall. The flames from the grates pass over the surface of the metal and emerge from the gathering holes, whence they pass upwards into a conical chimney. The metal is melted at night and is maintained during the day at sufficient temperature to be workable.

Another simple tank furnace, used in the Tyneside district, consists of a long narrow tank with a grate at one end and a flue at the other. The flames pass over the surface of the metal, but the heat obtained is not very high and is only sufficient to melt cullet.

Siemen's regenerative tank furnace is extensively used in the manufacture of common bottles. It consists of a rectangular tank roofed over with the arch of silica brick and provided along its side with ports for the admission of gas and air. One end is provided with filling holes and the other end is semicircular and is provided with working holes through which the metal is gathered. The batch is filled in at one end and is gradually melted. The molten metal gradually flows down to the working end and is refined on its way. Below the tank is situated the regenerator, chambers filled with brick checker work, which are alternately heated by the waste gases proceeding to the chimney and then cooled by the incoming gas and air which are heated by their passage through the regenerators.

The producers for making the gas are usually situated away from the furnace. Various types of producer are used, but in general they

consist of a vertical fire-box in which the fuel is burnt with means for filling the fuel from the top. The air may be drawn through the fire by the draught of the chimney or may be forced through by jets of steam directed below the grate. These tanks are of large size, holding about 100-120 tons of metal on an average. They work well and efficiently. There are a number of other patterns of regenerative tank furnaces and also a few in which the gas and air are heated by recuperators, but their number is so small that they are comparatively unimportant.

Only a few oil-fed tank furnaces are in use. The oil is vaporised by compressed air, and the flame from burners at the filling end of the tank plays over the surface of the metal.

After being made, most glassware must be annealed by being reheated in either kilns (or arches) or lehrs (continuous kilns).

A kiln or arch consists of a firebrick chamber which is heated by a fire usually made just inside its doors. After it has become sufficiently hot, the kiln is packed, the fire is drawn, the doors are closed, and the kiln is allowed to cool. The bottles are heated by radiation from the walls of the kiln and are annealed by slow cooling.

A lehr consists of a long tunnel, one end of which is heated by suitable means, the other end being cooled. The ware is stacked on trays which are drawn slowly through the tunnel, so that the ware is first heated and then slowly cooled. Sometimes the ware is placed on a band conveyer which forms the floor of the tunnel, and the band may be moved slowly by automatic means.

IV. Manufacturing Processes.

Although considerable progress has been made during the War, glass making is still, in the main, a manual process: that is to say, the formation of the article depends on the skill of the worker, although the skill is assisted by the use of such aids as moulds.

In blowing by hand, a workman gathers a mass of glass on the end of a blowpipe by dipping the end or "nose" of the pipe slightly into the metal, and then by rotating the pipe winds a quantity of the viscid mass on the pipe. The gather is withdrawn from the furnace and is then "marvered" by rolling it on a metal plate or stone slab in order to compact the gather and to form it into a suitable shape for subsequent working. The remaining operations depend on the class of article to be made.

In blowing bottles or moulded ware generally, the marvered gather is next blown to shape in a mould, and it is then detached from the pipe. The mouth of the bottle is formed by shaping the reheated neck by means of a tool.

In hand-made work, the marvered gather is reheated and blown out and is then given a suitable shape by tools, the perfection of the shape depending on the skill of the worker.

The employment of machines for forming glass is not extensive (although the trade is much more enlightened than before the War) and is confined to certain sections of the bottle trade and to the pressed table ware trade. The use of machinery, however, is increasing rapidly, and it is recognised that if the industry is to survive in the face of foreign competition, it can only be done by the extended use of machinery. A significant sign of the new spirit is the tendency for manufacturers to make periodical trips to the United States in order to gain new ideas by inspection of the admittedly more advanced processes employed there.

The semi-automatic blowing machine is practically the only type of machine employed in this country. Most machines of the type are tools rather than machines, in that all the operations are controlled by the operator, and the successful use of the machine depends on his skill and experience. The operator gathers a quantity of metal on a gathering iron and allows it to fall into a "parison" mould, wherein a "ball" or "parison" is formed. This "parison" is transferred to a finishing mould where it is blown to shape. The mechanism is employed in assisting transfer, in opening and closing the moulds, and the blowing is done by compressed air instead of by the lungs of the operator.

Other machines of this type are almost completely automatic, in so far as they only require one man and, perhaps, a boy to attend them, and the various operations are interlinked and do not depend on the skill of the operators. For example, all that the man is required to do is to feed the machine with glass which he has gathered on an iron, and all the judgment he is called upon to exercise is to decide when sufficient metal has fallen into the parison mould. He then operates a suitable switch and the rest of the operations are performed by the machine automatically.

Such machines can be made fully automatic by fitting a device to the tank by which the glass is allowed to flow automatically into the parison mould. Arrangements of this nature are already in operation in this country and others will be set to work in the near future.

There is only one fully automatic blowing machine at present in use in this country, the Owens, an elaborate machine of American origin. In this machine the metal is drawn up into the parison mould by suction. The moulds are mounted on arms which rotate about a central column, and vary in number from 5 to 15 according to the pattern of the machine. It is a costly machine and requires a staff of skilled engineers to attend to it, but when working properly turns out bottles or jars at a great rate. At the end of 1918 there were only a few of these machines working in the United Kingdom, but a number of others were in course of erection and more were on order.

The use of machinery, other than blowing machinery, is confined to dressing machines, cutting and grinding machines, and mixing machines. Pressed ware is generally made by forcing the metal into a mould by means of a hand-operated lever press. Such a machine is used for

making table ware, stoppers for bottles, lenses for railway lamps, signalling lamps, ships' lanterns, lighthouse lenses, deck lights and other bulky objects.

Small pots for containing foodstuffs are also made on a semi-automatic pressing machine of American origin, which only requires a gatherer to work it and is capable of being made fully automatic. Such machines are, as yet, little used in this country.

A great deal of hand-made ware is decorated by cutting before it is sent to the market. The " tools " or " lathes " used for this purpose consist of rotatory wheels of various materials which are armed with a suitable abrasive, such as sand. Stoppers are ground to fit bottles, chiefly intended for medical purposes, by means of rotating shafts to which the stopper or a grinding mandrel can be attached.

Mixing machines for mixing the materials of the batch are employed with considerable success. The usual type of machine consists of a horizontal drum containing rotating arms which stir the materials together. In some cases a device for grinding the batch is employed, but this practice is unusual, and there is a danger of introducing small quantities of iron into the batch and thus affecting the colour of the glass.

V. Raw Materials.

The principal raw materials are sand, sodium compounds (alkali and salt cake), calcium compounds (lime), potassium compounds (potash), and lead compounds. Other materials, such as colouring agents, are used in small quantities only.

For the finer grades of glass in which freedom from all colour is necessary, the sand is obtained from Fontainebleau, near Paris. This sand is remarkable, not only for its purity but for the evenness in the size of its grains, a quality which is very important in securing good glass. Before the War, other good sands were obtained from Belgium, but this supply ceased during the War.

Owing to the high cost of transit for the French sand and the increasing scarcity of shipping, attempts were made to find deposits of sand in this country which could be used to replace the French sand. Considerable success was obtained by using Aylesbury and Lynn sand, and very good colourless glass was produced. Other English deposits showing promise were found in the neighbourhood of Malton, in Yorkshire, and in Ireland.

For the commoner grades of glass, such as ordinary pale green or dark green bottles, the supply of sand presents no difficulty whatever, and some manufacturers of dark bottles whose factories are situated near the seashore use sand straight from the beach. Beds of sand suitable for common bottles are found inland at various places, as at Chelton in Kent, Leighton Buzzard, and at other places.

Consultation between the Optical Munitions Department, the Geological Survey, and the Geological Department of the Imperial College of Science and Technology in regard to British sources of supply, showed that the work already undertaken in the general interests of Imperial trade and industry required supplementing in order to find out the actual extent and quantity of the available sands in the United Kingdom, and in order that further chemical analysis of what might be termed second-class sands suitable for chemical glassware manufacture might be made. A short investigation as to how far crushed rocks of the type of felspar, for example, might be utilised in the successful production of good glass was also undertaken.

The Imperial College of Science and Technology agreed that Professor Boswell should undertake the work and complete it, provided that travelling expenses and costs of the analysis were paid by the Ministry, and his treatise, which was published in 1918, should prove of immense advantage to the trade.

Alkali, in the form of sodium carbonate, is obtained principally from Brunner Mond & Co., as is also the supply of "salt cake." Lime in the form of calcium carbonate is usually obtained from local chalk pits. For fine glass, a purer lime is obtained from the Buxton district, and marble dust is also used where obtainable. Potassium salts, chiefly the carbonate, were obtained from Germany before the war, and, in consequence, the manufacture of the highest grade of table and ornamental glass, crystal, was seriously affected. Potash, however, was being manufactured in England before the end of the war.[1] Lead, chiefly in the form of red lead, also enters into the composition of crystal, and of the glass used for electric lamp bulbs. Other materials used are arsenious acid for purifying the glass, manganese dioxide for decolorizing the glass, and various metallic salts for producing coloured glass. Broken glass known as "cullet" is always mixed with the batch as it melts at a lower temperature than the batch and facilitates its fusion.

In the small "crib shops" where small bottles are made in large quantities, only cullet is used and not batch. It is obtained from cullet merchants, who buy up broken bottles and other glass from marine store dealers, glaziers, bottlers and others.

A great proportion of the cost of certain materials such as the sand is represented by the cost of transit, so that facilities for transit play an important part in the industry.

VI. Control of the Glassware Industry.

At the time when the department was requested to develop the chemical glass industry the position was serious. The industry did not exist in this country before the outbreak of War, and supplies were mainly obtained from German and Austrian sources. Although at the outbreak of hostilities considerable stocks of German glass

[1] See below, pp. 71–90.

were held, these were rapidly exhausted, and but for the enterprise of one dealer and two manufacturers of other types of glass, the position in March, 1916, would have been even more serious than it was.

The department was also instructed to purchase the whole of the glassware required by the War Office, and it was decided that in order to safeguard War Office supplies, more especially those of the Army Medical Department, some more drastic form of control over the manufacture of the more important types of glassware would have to be put into operation. Already great difficulty had been experienced in obtaining Army Medical supplies, and it was felt that in view of the probable call upon the manhood of the nation and consequent labour shortage and the probability that the number of casualties would increase, steps should be taken at once.

Orders were therefore issued under the Defence of the Realm Regulations and Munitions of War Act on 2 January and 23 March, 1917, making it illegal for manufacturers to execute orders for certain types of glass and glassware unless such orders were approved by the Optical Munitions Department or a direct Admiralty, War Office or Ministry of Munitions contract was quoted. A consolidated Order was issued on 19 September, 1917, cancelling the previous Order.[1]

This control was largely a precautionary measure, which was approved by the majority of manufacturers and users.

The department obtained the right of refusing to pass any order if it was deemed necessary, and it frequently refused to pass orders in order to make firms concentrate on the government work they had in hand. This system of control also gave the department an opportunity of obtaining, by means of the returns from manufacturers and importers, accurate and detailed information of the state of the trade, which enabled it to give help at any point where it was needed.[2] Red lead was also allocated to the various glass manufacturers by the department.

VII. The Supply of Chemical Glass.

The supply of chemical glass and laboratory ware was before the War almost entirely in the hands of the Germans, and during the early part of the War we were similarly dependent on supplies from Sweden. As it was held essential that the country should, as soon as possible, be put upon a self-supporting footing, the Ministry of Munitions, in March, 1916, assumed responsibility for fostering and developing the trade.

The firm of John Moncrieff, Ltd., of Perth, had, since the beginning of the War, been developing the manufacture of certain classes of chemical glass and laboratory ware, but found themselves in need of financial assistance for further development. An agreement,

[1] See Appendix I.
[2] Copies of the forms and certificates are filed in HIST. REC./H/1930/1.

therefore, was concluded with them (20 June, 1916),[1] under which they received the financial assistance which they required, and in return they agreed :—

(1) To erect at their premises a furnace or furnaces for the manufacture of chemical glass capable of continuously dealing with not less than ten 36-in. pots of an average cubic content of not less than 2,000 lb. when full.

(2) To continue to produce such chemical glass for a period of ten years unless otherwise required.

(3) To maintain a proper and sufficient staff both for technical and for commercial purposes.

(4) To train and use the services of unskilled and female labour to the utmost extent possible.

(5) To maintain during the period of the agreement the furnace or furnaces in good order and repair, and not to dismantle them or use them for any purpose which would render them unfit for the expeditious and economical production of chemical glassware.

(6) To supply to Government Departments (when so directed) the whole or any part of the chemical glass manufactured.

(7) To observe the Fair Wages resolution passed by the House of Commons on 10 March, 1909.

(8) Not to employ anyone who was not a natural born British subject without the permission of the government representative.

In consideration of the firm's adhering to the terms of the agreement, the Ministry of Munitions agreed to advance £10,000 carrying interest at a rate of five and a half per cent. per annum, the sum to be repaid in equal half-yearly instalments, the first instalment being payable on 31 December, 1919, and the last not later than 30 June, 1926. The firm had the option of repaying the whole of the sum outstanding at an earlier date.[2]

Two other agreements on similar lines were entered into with other firms to ensure the supplies of scientific glassware. In all three cases provision was made for a government representative with the same powers as those conferred under the optical glass agreements.[3]

VIII. Clay Research.

In June, 1916, it was felt that the supply of glass pots in the United Kingdom was in a critical position, and it was decided to commence scientific research along the three following lines :—

(1) Scientific analyses of the clays used in pot-making, and based on these the preparation of formulæ as to the most suitable composition and texture to be used in the construction of pots for the different classes of glass-making.

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[1] C.M.6/60534.

[2] A second agreement with this firm was signed on 16 July, 1917. O.M.G./GEN/1786 A.

[3] See above, p. 11.

(2) The preparation after examination of a standard series of time plus temperature curves for the drying out and maturing of pots preparatory to their treatment in the pot-arch so that the minimum time for maturing both chemical and optical pots might be clearly established.

(3) The preparation after examination of a standard series of time plus temperature curves for the treatment of pots in the pot-arch and preparatory to their use in the furnace.

Sir Herbert Jackson, of King's College, London University, agreed to place his services at the disposal of the Ministry of Munitions without fee, but as there were necessarily other expenses involved in connection with the research work, a grant of £1,000 was made to cover such expenses. The objects of the research were :—

(1) To reduce the time allowed for the maturing of glassware pots.

(2) To diminish breakage, and thus to effect a substantial increase in the output of glass.

Considerable progress was made in connection with this research work.

The types of crucible mainly used in connection with the manufacture of glass are known as "covered" or "dog-house," "skittle," "cannon" and "open" pots. The "tank-furnace" is in effect the latter vessel extended to the form of a huge firebrick tank capable of holding 50 to 100 tons of metal and is designed for use in the manufacture of bottles and other cheap qualities of glass.

In the production of table glass "covered" or "dog-house" pots are invariably employed, the object being to protect the metal from the action of furnace gases and other compounds of a volatile nature evolved in the furnace during working hours. The quality of the pot is associated with the quality of glass in exact ratio, and the purity and strength of the clay from which the pot is made may be regarded as a *sine qua non* in the manufacture of pure glass. To this end the aim of the potmaker has been to produce his vessels from the finest fireclay he could command, and up to recent times such clays were taken, and were supposed only to be found, almost exclusively in the fireclay beds of the Stourbridge district.

Investigation proved, however, that while the clay seams in these well-known measures are of extremely high quality, there were other fireclays in England and Scotland which promised as good results. This is of importance, because the exhaustion of the finest Stourbridge seam is within view, while the still unworked areas are in the hands of a very limited number of firms who are in a position to exploit the material in a manner not infrequently adverse to the production of glass. It was also ascertained that there were possibilities of improving the nature of fireclay by artificial means.

In order to suggest industrial processes for the improvement of the general properties of pot clays, the whole question of refractory materials for glassware manufacture had to be investigated.

The earlier experiments may be described as tentative and directed towards obtaining an understanding of the real nature of the problems involved. They included the investigation of some 24 varieties of clays. The properties of these clays were studied in respect of (*a*) the rate of subsidence of the ground clays mixed with a large bulk of water, the influence of alternate heating and cooling on this rate, as well as the modifying effect of small quantities of acids, alkalis, including ammonia, and substances such as ammonium oleate, sodium silicate, etc., (*b*) the absorptive powers of the clays for colouring matters of various kinds, and (*c*) the extent and rate of oxidation of raw clays by aqueous solutions of oxidising agents, *e.g.*, potassium permanganate.

Deductions from all these experiments may be summarised here.[1]

It was found :—

(*a*) That alternate changes of temperature on lumps of tempering clay appeared to hasten the process of tempering.

(*b*) That if a clay showed no, or only a very few fine particles under the microscope, it would not pull long. For instance, kaolin, which is almost free from any but relatively large and crystalline particles, could be tempered so as to show the plastic behaviour of a good pot clay and certainly none of that shown by a ball clay. The general appearance under the microscope of some ball clays strongly resembled that of the finer portions of good pot clays, and the clay had a similar general composition. Some ball clay which was examined showed little or no sign of fusion at a temperature at which many pot clays fuse to a glass.

(*c*) That small quantities of alkalis, including ammonia, as well as substances like sodium silicate and ammonium oleate, assisted in bringing about the condition of clays associated with good plasticity, also that many organic colloidal solutions had a similar effect in maintaining the state of freedom of the particles of the clay and in neutralising the opposite effect of mineral acids or metallic salts which may be present in the clay or formed during tempering. Straw infusions were used for this purpose, and infusions of peat acted in a similar manner. When there is an abundant source of good pot clays which behave satisfactorily without any special treatment, it is unnecessary to try the treatments suggested in (*a*), (*b*) and (*c*) ; but there exist clays which would have been condemned on the existing criteria of suitability, which on investigation might be found amenable to some method of treatment with good results.

Experiments and investigations were still proceeding at the date of the Armistice, and it was anticipated that by means of a new process for treating clays for pot-making the main difficulties would be completely overcome, both from the point of view of utilising clays

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[1] See Appendix V. for a fuller summary.

previously thought unsuitable, reducing the time of manufacture by 50 per cent., and improving the life and commercial value of the pot.

IX. Control of Manufacture of Glass House Pots.

After studying the question of the manufacture of pots for a sufficient time to enable the branch to acquire a thorough understanding of the matter, a complete and exhaustive census was taken throughout the whole country of the stocks of pots, of the requirements of the glass manufacturers for these articles, and of the potential output of the manufacturers of pots. The information obtained revealed the fact that unless drastic action was taken there would be a shortage of pots which might result in serious consequences both as regards the output of optical glass and of other types of glass required for essential purposes.

Steps were immediately taken to arrange for the building of a new factory, and the most stringent form of control over the manufacture and distribution of pots was put into operation. Probably for the first time glass manufacturers were compelled to order their pots in such a way as to enable the Glassware Branch to arrange for the delivery of a certain number of them each month. Previously orders had been given to the manufacturers to supply a fixed number of pots, which in some cases were not delivered until nearly two years after the order had been placed. Though it was generally thought that a pot did not mature until twelve months after the completion of its building, before the manufacture and supply were controlled by the Ministry pots were being sent out which had only been matured two and three months; this being insufficient, the life of the pots was in many cases very short.

After investigation it was decided that no pot should be allowed to be despatched by a maker unless it had been matured for four months. Instructions were issued that all pots made in future must be marked with the date on which building was completed, so that the glass manufacturers were aware of their ages.

All glass manufacturers were required to render a statement of their requirements of pots to the Optical Munitions Department, together with particulars as to whom they desired to obtain them from. These returns were compared with those received as regards stocks and potential output from the pot manufacturers and resulted in a considerable transfer of orders, which would never have been executed by the firms it was desired to obtain them from, to other firms who were able to satisfy the consumers' requirements.[1]

The result was that the most critical period was passed without disaster, and by the later months of 1918, although the position warranted continued control over the manufacture and distribution of pots, serious anxiety was no longer felt as regards the future.

[1] Copies of the forms and certificates used are filed in HIST. REC./H/1930/1.

X. The Various Divisions of the Glass Industry.

The glass industry includes the following divisions :—

Scientific glassware ;
Illuminating glassware ;
Machinery glassware ;
Tubing and rod ;
Plate and sheet glass ;
Domestic and fancy glassware ;
Bottles and jars ;
Protective glasses for instruments.

Scientific Glassware.

Scientific glassware includes all chemical, medical, surgical and bacteriological glassware other than bottles ; it can be subdivided into furnace-made and lamp-blown glassware.

Almost without exception, the furnace-made scientific glassware used in this country before the war was obtained from Germany and Austria. As regards lamp-blown scientific glassware, there were a few small firms in this country capable of executing repairs and making a limited number of orders of special design, and a few makers of clinical thermometers who, as a general rule, were men of slender means working in garrets under most unhealthy conditions. Beyond these, the requirements of the nation were met by supplies from Germany and Austria.

For some time after the outbreak of war the nation existed on the substantial German and Austrian stocks which dealers had accumulated. At a later date these were supplemented by limited supplies from Scandinavia, which were in some instances of German manufacture, while the position with regard to some essential types of scientific glassware such as X-ray tubes was saved by importing from America. In other cases glassware of inferior quality was utilised until British firms were prevailed upon to begin manufacturing.

Before manufacture could begin in this country, however, a considerable amount of research work was necessary. This was done to a certain extent by the firms themselves, but to a large extent by Sir Herbert Jackson—at first on behalf of the Institute of Chemistry, and later in his capacity of Scientific Adviser to the department—and by the department's own scientific staff.

The problems that had to be solved before this ware could be produced successfully in quantity are

(1) the production of a suitable glass ;

(2) the manufacture of vessels with very thin walls of even thickness (beakers) ;

(3) the production of tubing with very thin walls for test tubes ;

(4) the training of workers to the shaping of glass in the blowpipe.

The first two problems presented the greatest difficulty, but compositions of suitable glasses were determined by Sir Herbert Jackson, who succeeded in producing glasses which formerly were mainly obtained from Germany.[1]

For the second problem, the worker in hand-made flint glass had to be depended on, but certain firms, looking to the future, began training boys. Of course, the ware produced at first was not equal in quality to the German ware, the production of which was the result of accumulated experience, nor was it possible to sell it at so low a price. Quality steadily and rapidly improved, however, and the output also increased steadily.

This research work had to be supplemented by experimental work in the factories, which was done by the manufacturers at their own expense. But for their patriotism the glassware necessary for the manufacture of steel, explosives, munitions and other war material (including sea mines used in defence against enemy warships and submarines), for the Army Medical Service, for hospitals in this country, for civil medical work and for many essential industries, would not have been available.

Early in 1916 the Board of Trade, which had for some time been investigating the situation and had realised the very serious state of affairs which was likely to arise unless special action was taken, approached the Ministry of Munitions with a view to its taking responsibility for developing this section of the industry, and as the result of negotiations between the Board of Trade, Admiralty, War Office and Ministry of Munitions, an official letter was written on 20 March, 1916, by the Board of Trade to the Ministry of Munitions, stating that the Board would welcome any action which the Ministry might be able to take " in the direction of promoting the chemical glassware industry."

The expression " chemical glassware " was used at that time for want of a better term. As, however, for manufacturing purposes, there is no distinction between chemical, medical, surgical and bacteriological glassware, the term " scientific glassware " has been adopted as being more suitable.

In assuming responsibility as a supply department for the provision of chemical glass, one of the difficulties the branch had to overcome was in connection with the production of certain non-commercial types of glass, which, although essential to the production or examination of certain munitions, were not required in great bulk, in several cases a few pounds weight sufficing to meet annual national requirements. These types required the utmost care in making to ensure special qualities, and in some cases the suitable formulæ had to be arrived at by trial, but during the War it was impossible for makers to undertake this research work, their time and furnace room being already occupied on bulk supplies of urgency.

[1] Special investigations were undertaken by Sir Herbert Jackson to facilitate the manufacture of X-ray tubes, and of mine horn battery containers.

Sheffield University, however, with the assistance both financially and technically of local manufacturers, and with some financial assistance from the Advisory Committee of the Privy Council, organised classes for the technical instruction both of workmen and of the more highly skilled directing grades. The University invited the assistance of the Ministry, and it was agreed that to make the work effective the provision of plant of a semi-commercial character, including a furnace constructed on the most modern lines, was essential. It was proposed to utilise this furnace to produce the special descriptions of chemical glass previously referred to, and to carry out this programme a grant of £3,000 was made, in consideration of which the University and the Glass Technology Department Delegacy undertook:—

(1) To erect the plant and buy materials to plans and at the cost approved by the Ministry of Munitions.

(2) To use the plant for the purpose defined by the Ministry of Munitions if desired for a period until six months after the declaration of peace, provided that the Glass Technology Department was permitted to conduct special tests and investigations on behalf of the industry, in so far as these would not interfere with the effective prosecution of investigations conducted on behalf of the Ministry of Munitions.

(3) To place the products made by the plant in the hands of the Ministry of Munitions for disposal as the Ministry should think fit.

(4) To treat information, formulæ and methods obtained at the request of the Ministry as secret, and to place them at the disposal of the Ministry.

(5) To conduct researches under the directions of the Ministry of Munitions in such a manner as to prevent overlapping.

(6) To pay the salaries of the staff other than workmen or labourers.

The specific glasses for which the research work was undertaken were:—

(1) Good coloured glasses for the adequate protection of gunners' eyes from the injurious effects of flash.

(2) A good uviol (used in spectroscopes), which was then unobtainable.

(3) A moderately soft uranium glass of a highly fluorescent character.

(4) A bright scarlet glass both opal and clear.

(5) Neutral tinted optical glasses.

(6) A very high density, low fuzing glass of high refractive index.

A great deal of analytical work was involved. Most of the glasses required had been imported and the first step towards their reproduction in this country was a complete quantitative analysis, and a series of small scale trial meltings, over 2,000 being made by Sir Herbert Jackson.

The result of the department's activities was a great increase in production. Starting at practically nothing, the turnover of the scientific glassware section of the industry was increased to more than £600,000 per annum by the middle of 1918.[1]

ILLUMINATING GLASSWARE.

Glassware for artificial light may conveniently be divided into :—

(*a*) Glassware which forms an essential component part of illuminating apparatus.

(*b*) Illuminating accessories.

The chief items falling under the former group are glasses for miners' safety flame lamps, glass bulbs, tubing and rod used in the manufacture of electric lamps and oil lamp chimneys.

Before the War the whole of the glasses for miners' safety flame lamps and oil lamp chimneys, and 75 per cent. of the glass bulbs and tubing and rod for electric lamps were obtained from abroad, mainly from Germany and Austria.

In November, 1914, the Home Office found it necessary to relax the very stringent conditions which up to that time had been insisted upon with regard to the quality and dimensions of glasses for miners' safety flame lamps, owing to the impossibility of obtaining supplies. Ultimately, they came to the Ministry of Munitions for assistance, and notwithstanding the extraordinary difficulties met with, it became possible to prohibit the manufacture and importation of unapproved glasses, while it was proposed that the use of any unapproved glasses should be prohibited as from 31 March, 1919. This was rendered possible by the development in the production of approved glasses under the supervision and direction of the department.

Before the war practically no chimneys for oil lamps were made in this country. For some considerable time after the outbreak of war the country managed to exist on chimneys imported from Allied and neutral countries and on the large stocks of German and Austrian chimneys held in the country. Later on, however, owing to the exhaustion of these stocks and to the shipping restrictions following America's entrance into the war, the position became exceedingly serious and the department had to take very special steps to arrange for manufacture in this country. The position still caused anxiety in 1918, owing to the shortage of labour and plant, and very careful control over the distribution of stocks was necessary.

[1] C.D./9035.

Bulbs, Tubing and Rod.

The glass bulbs, tubing and rod used in the manufacture of electric lamps were before the war obtained from Germany to a very large extent. Even those electric lamp works in this country which had their own glassworks obtained large supplies from Germany and had established glassworks in this country merely as a precautionary measure. After the outbreak of war, supplies of bulbs, tubing and rod were obtained from Scandinavia and Holland, but when shipping space became short and imports had to be restricted, steps had to be taken to produce the whole of the requirements within the country.

Starting from a pre-war output of approximately 12,000,000 per annum, British manufacturers were, in 1918, producing at the rate of approximately 47,000,000 bulbs per annum, with a corresponding quantity of tubing and rod. No bulbs were imported during the latter part of the war. F. P., the metal used for electric lamp bulbs, contains lead and must be so colourless that there is no perceptible loss or tinting of the light passing through the bulb. The metal must also be able to stand subsequent working in a blowpipe without cracking or changing its character. As the metal contains lead it is melted in covered pots. No special type of furnace is used, in fact there is almost a different furnace for each factory. Blowing is done by hand, the blower twirling his pipe as he blows the bulb in the mould in order to prevent mould marks from showing on the finished bulb.

Machines for blowing bulbs are already working in this country and a few others are in course of erection. With this machine a man gathers the metal on a pipe which he places on the machine. The machine then completes the operation. For some time yet, however, hand labour must be used for making bulbs and the question of increased supplies is one of increased labour. It is possible to train boys to do the work in a comparatively short time. A boy should make saleable bulbs in three months and should be working at an economically efficient speed in eighteen months.

Glass tubing is made in quantities for use in laboratories, and the recommendations made by Lord Balfour of Burleigh's committee[1] with regard to chemical glassware would apply equally well to these types.

Sooner or later machinery will undoubtedly be installed for the manufacture of bulbs and oil lamp chimneys, and as soon as the country has been completely equipped in that respect much of the State assistance could be abandoned.

Machinery Glassware.

The position with regard to machinery glassware—gauge glasses, lubricator glasses, and glass used in textile machinery—was fairly secure. British manufacturers before the War not only held the British markets but also had an export trade. To ensure the best results in the future, all that would be necessary would be for a Government Department to advise on improved methods of production and to render any other assistance that might from time to time be necessary.

[1]See below p. 70.

PLATE AND SHEET GLASS.

The manufacture of plate and sheet glass in this country is in the hands of two firms, except that there are two other small and unimportant firms manufacturing coloured sheet glass. Before the War Belgian manufacturers, largely financed by Germans, supplied a large proportion of the British demands. The bulk of the European plate glass manufacturers had agreements with one another, and thus formed a strong ring. Messrs. Pilkington, the only British manufacturer of polished plate glass, was outside this ring, but maintained the same prices. During the War, essential supplies of these types of glass were maintained with difficulty and at the expense of some of the less essential supplies, and only because window glass was no longer required for new houses. Considerable quantities were used in the construction of national and other war factories, army huts, and in replacing breakages as the result of air raids.

Photographic glass for the Royal Air Force was also required in increasing quantities, and a similar type of glass was used for gas masks and goggles for airmen and for triplex safety glass screens for aeroplanes.

DOMESTIC GLASSWARE.

The manufacture of flint glass hand-made ware is the oldest branch of the trade and from it all other branches have developed. The ware made ranges from lamp shades of simple pattern to the most beautiful and costly decorated ware, and owing to the variety of articles that he is called upon to make the blower must and does attain a high degree of skill. The decorating is a highly skilled occupation, the worker having to hold the article in his hand while pressing it against the rotating wheel and guiding it to produce the pattern.

The great majority of the firms engaged in this trade are located in Worcestershire and Warwickshire, chiefly in Stourbridge and its immediate neighbourhood. Certain grades of ware formerly made by hand tend more and more to be made by pressing machines, and certain American processes of pressing, followed by slight cutting and polishing, threaten to reduce the demand for hand-made ware in the future. The pressed ware branch of the trade is mainly located in Tyneside and Wearside, where table ware and drinking vessels of the cheaper kind are produced in great quantity.

The glass is a soda-lime metal and is melted in very large covered pots. The process of manufacture consists in first pressing out the article in a mould by means of a hand-operated press, then polishing or glazing the article by exposing it to a fierce flame in a "glowry hole" or "glory hole" and finally modifying the shape, if necessary, by hand.

The best quality of table ware, especially that which is cut and otherwise decorated, has for many years been manufactured successfully in this country and there was a fair export trade. Of late years, foreign competition, particularly in Sweden, France, America and Austria, had made considerable headway; the quality was becoming

almost as good as the British glass, and the price was usually much lower. But for the War, there is no doubt that British manufacturers would have before long seriously felt this competition. Their methods of production were and are generally the same as were used more than a hundred years ago. In some instances new processes have been introduced, but these have not so far been developed to the extent they should have been.

During the War, manufacturers of table ware have been put on to other work, such as scientific glassware of the heavier type and bulbs for electric lamps, and they appear to have awakened to many of their shortcomings.

Before the War, the cheaper types of table ware were imported from Belgium, France, Sweden, Norway and Holland. As the result of the German occupation of Belgium and restrictions of imports, the Ministry had to take steps to increase output of the commoner types for the use of the Navy and Army and Government Departments. Towards the end of 1918 it appeared that for some time to come Government requirements would absorb practically the whole of the British production, and complaints were being made from certain munitions areas of the shortage of drinking glasses.

In due course the country will be equipped with machinery for the manufacture of tumblers, but as such machinery would not be efficient until the whole of the plant had been modernised, the department thought that, during the period of reconstruction, some protection ought to be afforded in the form of an import duty, and that a Government Department should be available to advise in matters relating to manufacture and to assist the industry generally.

On the other hand ornamental and cooking glassware, being unessential, should need no assistance other than was considered necessary from the point of view of encouraging British manufacture and protecting British labour. During the War manufacturers of this type of glassware were largely engaged in the manufacture of both scientific glassware and the essential types of illuminating glassware.

BOTTLES AND JARS.

The largest trade in the glass industry is the common bottle trade and its importance is shown by the fact that the glassmakers of all ages were still in reserved occupations in the list of 16 November, 1916. The ware is increasing in demand, as there is a general tendency to prefer a glass container for food to one of tin. The trade is chiefly centred in Yorkshire and Lancashire, although factories are spread all over the country, especially in places where there is a big local demand. A factory is often of large size and may cover several acres of ground. The metal is melted in tank furnaces heated by producer gas, and semi-automatic machines are used to a fair extent. The larger firms have been induced to turn their attention more and more to production by machinery, and a number of Owens machines are on order or in course of erection.

The large scale on which the ware is produced tends to bring firms into close relationship, and there are already groups of firms which are really under one ownership although they continue to trade under separate names. In addition, practically all the firms in this branch of the trade are combined in one association, the British Bottle Makers' Association. This combination was formed for the purpose of regulating output and prices, and has concluded agreements with similar combinations in other countries regarding the importation and export of bottles. It also controls the Owens machine in this country. The men's trade unions are also concerned in the combination and no firm outside the combine can secure union labour.

The flint bottle trade concerns itself with small bottles, particularly those made of quite colourless glass, as well as those of coloured glass. A large number of such firms are found in London, and these London factories, known as " Cribs " or " Crib shops," almost entirely use skittle pots and coke furnaces of the simple type described above.

In the North of England, a simple tank furnace is often used, although furnaces employing both open and covered pots are also used. The manufacturers are associated in a national union and also in local associations, such as the Yorkshire Association of Flint Glass Bottle Manufacturers.

Before the War, large quantities of bottles and jars were imported from Germany and other countries. During the War the demand for glass containers for foodstuffs increased greatly, and at the request of the Food Production Department of the Board of Agriculture and Fisheries, and of the Ministry of Food, the Optical Munitions Department stimulated the output of two classes of food containers, namely, fruit-preserving jars and containers for preserved meat.

Fruit jars were little used in the country before the War, but the increased demand during the War is shown by the following figures of production :—

1912	11,953 dozen.
1913	12,368 ,,
1914	22,317 ,,
1915	Not available.
1916	47,002 dozen.
1917	166,666 ,,
1918	833,333 ,,

From reports received, there is no doubt that this form of fruit preservation has come to stay, and will necessitate an increased output of glass to satisfy the demand.

Meat preserving jars were practically all imported before the War, but the shortage of shipping space, together with the anxiety of the Ministry of Food to preserve meat that would not otherwise be used, necessitated a greatly increased output of this class of ware.

It was anticipated that the Ministry of Food campaign for purer milk, involving the provision of a glass bottle that can be cleaned and sealed, would lead to an enormous demand for these bottles which would necessitate the erection of several new factories. When the War broke out this section of the industry was in the midst of the process of transfer from hand manufacture to machine manufacture, but owing to the existence of agreements between employers and men as regards the selling prices, and to the impoverished conditions of manufacturers, the transfer was slow before the War, and during the War it was not expedited to the extent it might have been, had it been possible to obtain machines. The material and labour necessary to produce such machines were generally required for actual munitions of war. The position was further complicated by certain agreements with a German company owning the European rights for the Owens machine. It was suggested that, if the industry was to be maintained, some form of safeguard might be necessary during the completion of transfer to machinery and the modernising of plant.

XI. The Future of the Industry.

Manufacturers are unanimous in stating that before the War the whole trade was slowly dying by reason of German competition. In particular, German-made bottles could be sold in this country at less than the wages cost of the native product. By 1918 there had been a great rise in wages over the 1914 level, and manufacturers regarded the future with something akin to fear. A new competitor, Japan, had lately come into the field and promised to be most formidable.

The greatest need of the trade was labour, as the country's demand for ware, particularly for bottles, was greater than its output. Firms depended a great deal on getting back their former employees on the cessation of War, but it was recognised that many would be killed or maimed, and it would take time to train others to fill their places. A difficulty in doing this arose from the fact that boy labour was scarce in the industrial districts where the manufacture is mainly situated, and that boys tended to prefer the high wages which were offered during the War in all sorts of ephemeral occupations rather than the low wages accompanying apprenticeship to a skilled occupation.

The Optical Munitions Department urged that the increase of output which is demanded by the country's needs could only be satisfied by the increased employment of machines, but many of the small firms (who make up so much of the trade) were reluctant to spend large sums on expensive machines in the face of an uncertain future, and also of the veiled hostility to machinery displayed by certain sections of the men.

Most of the best machinery used in the manufacture of glass in this country has been designed and manufactured in America. In the view of the Optical Munitions Department, if the glass industry is to hold its own in the future, steps should be taken to create a glass

machinery industry in this country, manufacturing on a large enough scale to attract the best brains. It was not possible to do this during the War, except that a few simple types of machines were made, and large sums were paid for the British rights of American machines, which might have been designed in this country at less expense.

It appeared desirable for the whole question of the employment of machinery to be considered by some official body which would be prepared to give both moral and material aid to those firms who were prepared to modernise their methods.

The future of the scientific glassware industry was specially important. Even at the end of the War the supplies of scientific glassware were barely adequate for war purposes, and it was clear that if the output of war material, including that required for the American Forces and Allied Armies, continued to increase, much larger quantities of scientific glassware would be needed. The department pointed out (September, 1918) that supplies of medical apparatus would be required for a considerable time after the conclusion of hostilities both for the Forces, including the American and Allied Forces, and for civil purposes; that steps must be immediately taken to deal with the questions of after the war trade; and that so many other industries were dependent on supplies of scientific glassware that its efficiency was a necessary preface to their reconstruction. The department admitted that the industry was not then efficient, although under certain conditions there was every prospect of it being made so.

The energies of both the department and manufacturers had been largely devoted to the production of glassware which would perform the functions for which it was required, but it had not always been possible to introduce the most efficient methods of production or to produce material which could claim to have anything better than a war finish. While it was perfectly true to state that scientific glassware had been produced in this country which was as good as or even better than Jena glass, it would be foolish to pretend that the quality was generally equal to that of Jena.

Improvement in quality and reduced cost of production would be obtained as the result of further research, and as the skill of the workmen increased the methods of production became more efficient. It was important that the research work should be supervised by an impartial Government Department having accurate knowledge of requirements which would obviate the risk of effort being expended on matters of secondary importance to the detriment of those of vital importance. For example, manufacturers of glass tubing, which is used as the raw material for lamp-blown scientific glassware, had not yet seen the advantage of producing tubing of standard quality, and consequently had conducted no researches with that object. From the point of view of the users of the tubing, however, this was an urgent problem which should be dealt with the moment an opportunity presented itself.

Other research, which might be necessary to produce specific types of glass used only in small quantities, but nevertheless of great importance to the country, could only be done under the direction of a Government Department familiar with the conditions. Having regard to the enormous variety of articles required, and the comparatively small quantity of each type, it was unlikely that machinery would be used throughout the whole process of manufacture in this section of the industry, and therefore British manufacturers would always be at a disadvantage as regards cost of production so long as the skilled men were paid higher wages than in other countries and output was limited by trade union rules. Much, however, could be done by adopting the most efficient methods of production, under the advice of a Government Department which had the opportunity of examining methods of production in this and other sections of the industry.

A report of Lord Balfour of Burleigh's Committee on Commercial and Industrial Policy after the War, which regarded scientific glassware as a " key " or " pivotal " industry " essential to the future safety of the nation," may be quoted :—

> " We are satisfied that the continuance of commercial and scientific assistance and of detailed control on the lines already followed will be necessary for a considerable period. It is clear, moreover, that in order that the industries may have time and opportunity to adapt their organisations to peace conditions and to train an adequate supply of skilled workers, very special measures of protection against foreign competition will be required at the outset, in view particularly of the great strength and reputation of German firms. Having regard to the peculiar circumstances of the industries in question, we think that these measures will be regulated most effectively by means of the prohibition of imports from whatever source, except under licence, of certain kinds of glass and optical instruments to be specified from time to time.
>
> " It will clearly be necessary that a Government organisation should be continued in existence charged with the supervision and promotion of the glass industries. Control of prices and methods of manufacture should continue to be exercised as at present."

CHAPTER IV.

POTASH PRODUCTION.

I. Imports of Potassium Compounds in 1913.

During the second year of the War one of the results of Great Britain's pre-war economic dependence upon Germany for essential commodities became evident in the shortage of potash. The optical glass industry found itself in need of supplies of refined carbonate of potash; the stocks which had been held in the country were coming to an end, prices were rising sharply, and it was absolutely essential, if only for the production of such military optical requirements as gun-sights, telescopes, periscopes, and so forth, that a new source of supply should be found as soon as possible.

It is a matter of common knowledge that before the War Germany had supplied practically the whole world with potash, owing to the fact that enormous natural deposits occurred within her territory. It was merely a matter of mining and of commercial organisation to produce salts of potash in enormous quantities and at prices which no one else could touch. The organisation which was developed took the form of the Kali Syndicate, which had the powerful backing of the German Government behind it.

In 1913 the total sales of German potash amounted to 11,102,740 double cwt. (1,110,274 metric tons), the estimated value of which was 202,000,000 marks (£10,100,000). In the same year potash salts to the value of £1,380,567 were imported into Great Britain, the German contribution to this being over £915,867. The exact meaning of these figures is shown in the following table (p. 72), prepared from Board of Trade figures.

The table shows how enormously imports from Germany predominated; also that we imported a number of refined salts from France, Belgium and the Netherlands, carbonate of potash from Russia, iodide from Japan, cream of tartar from Italy and Portugal, saltpetre from India, and small quantities of other potash materials from other countries.

It will be seen from these figures what a serious problem the Ministry of Munitions had to face when the importation of most of these compounds was cut off. No deposits of potash salts similar to

THE VALUE OF IMPORTS OF POTASSIUM COMPOUNDS INTO THE UNITED KINGDOM, 1913.

Potassium Compound.	Belgium.	Canada.	Germany.	France.	India.	Italy.	Japan.	Netherlands.	Portugal.	Russia.	Sweden.	U.S.A.	Other Foreign Countries	Total.
	£	£	£	£	£	£	£	£	£	£	£	£	£	£
Bromide ..	—	—	—	—	—	—	—	—	—	—	—	799	—	8,626
Carbonate ..	1,314	3,464	33,555	8,473	—	—	—	—	—	58,499	—	603	—	105,908
Caustic ..	8,827	644	79,090	12,832	—	—	—	—	—	—	1,551	899	—	103,843
Chlorate ..	3,328	—	2,101	14,020	—	—	—	—	—	—	6,595	—	—	26,044
Cream of Tartar	—	—	149,562	130,057	—	21,198	—	23,980	5,533	—	—	—	—	330,330
Cyanide ..	—	—	9,763	—	—	—	—	—	—	—	—	—	—	9,763
Iodide	—	—	10,351	—	—	—	30,654	—	—	—	—	—	—	41,005
Kainit	—	—	117,994	—	—	—	—	6,524	—	—	—	—	—	124,518
Lyes	—	—	8,762	—	—	—	—	—	—	—	—	—	—	8,762
Muriate ..	—	—	99,951	—	—	—	—	—	—	—	—	—	—	99,951
Pearlash ..	—	—	—	1,842	—	—	—	—	—	—	—	—	—	1,842
Perchlorate ..	—	—	—	1,242	—	—	—	—	—	—	3,880	—	—	5,122
Permanganate ..	—	—	7,451	—	—	—	—	—	—	—	—	—	—	7,451
Phenylglycine ..	—	—	38,832	—	—	—	—	—	—	—	—	—	—	38,832
Potash	—	230	—	—	—	—	—	—	—	—	—	—	—	230
Prussiate ..	3,244	—	14,781	15,201	—	—	—	—	—	—	—	—	—	33,226
Saltpetre ..	25,023	—	156,682	—	56,631	—	—	—	—	—	—	—	1,571	239,907
Sulphate ..	1,313	—	85,175	1,601	—	—	—	—	—	—	—	—	—	88,089
Sulpho. Muriate	—	—	22,935	—	—	—	—	—	—	—	—	—	—	22,935
Waste Salt ..	—	—	50,193	—	—	—	—	2,582	—	—	—	—	—	52,775
Miscellaneous ..	2,563	62	20,862	1,904	—	—	—	1,040	—	—	608	645	3,724	31,408
Total ..	£45,612	4,400	915,867	187,172	56,631	21,198	30,654	34,126	5,533	58,499	12,634	2,946	5,295	1,380,567

the German deposits had been discovered anywhere in the British Empire, and there was no production whatever within the British Isles, except for a very small quantity produced by kelp burning on the northern coasts of Scotland and Ireland. Within the Empire, India could supply nitrate of potash sufficient for the country's war-time needs. The handling of nitrate was, throughout the War, dealt with by the Explosives Supply Department, although towards the end of the War the Potash Branch furthered the development of the manufacture in India of carbonate of potash from nitrate and its importation into this country.

It was accordingly necessary to find entirely new sources of supply. In the Optical Munitions Department the need first became manifest owing to the requirements of the glass industry for pure carbonate; but the greater need of agriculture for potash very soon became obvious. It was estimated that Great Britain required at least 30,000 tons of potash manure per annum, potassium salts being particularly necessary for flax, potatoes, and leguminous crops. The medicinal needs of the Army for potash had also to be met; dye, soap, cocoa and match manufacturers all required potash,[1] and the demands of other industries were estimated at 800 tons of different potash salts per annum.

II. Scheme for Production of Potash from Blast-Furnace Dust.

In 1916 part of the carbonate of potash required by the Optical Munitions and Glassware Department of the Ministry was being supplied by the British Cyanides Company, Ltd., Oldbury. This brought Mr. Kenneth Chance, a director of this company, into touch with the work of the branch, and led to his laying before the late Mr. A. S. Esslemont, then Director of Optical Munitions, details of investigations that he had been carrying out in conjunction with others on the possibility of recovering potash from blast-furnace dust.[2]

In the autumn of 1914, an advertisement had been inserted in the technical press by the North Lincolnshire Company offering for sale the dust collected from their blast-furnace gases by their newly installed gas-cleaning plant. This advertisement attracted the notice of the British Cyanides Company, who made arrangements with the North Lincolnshire Company by which a joint investigation upon the possibilities of producing the dust and working it up into commercial products was undertaken. In April, 1915, the first investigations were made, but owing to alterations in the plant it was not until early in 1916 that direct experiments could be begun. The final result of the work done by Mr. Chance and Mr. Lennox Leigh, of the North Lincolnshire Iron Company, was the process (subsequently patented) of adding a small quantity of salt to the charge of the blast furnaces. It was found that this served to release the potash in the original charge and

[1] The dye industry required some 1,000 tons of caustic potash annually.
[2] An outline of the process is given in Appendix VI.

cause it to be volatilised in the hot gases from which it could be separated by the use of appropriate gas-cleaning plant. Owing to the fact that the potash was present in greatest quantity in the finest part of the dust carried by the gases, it became necessary to adopt the most efficient system of gas-cleaning then known. Large scale tests of the Chance process conducted during a considerable period led to the conclusion that it was not only successful in releasing very large quantities of potash in the dust, but also that it was in no way deleterious to the quality of the pig-iron produced or to the lining of the furnaces. Mr. Chance and Mr. Esslemont were in constant communication during the early part of 1917 with reference to this work, and it was decided that blast-furnace dust promised to be the most important British source of potash. Mr. Chance estimated that it would be possible to recover by suitable means a maximum of 50,000 tons of potash salts per annum from blast-furnace dust alone, enough practically to meet the needs of the country.

The suggestion to develop a British potash industry with blast-furnace dust as a raw material was placed before Dr. Addison as Minister of Munitions, and in June, 1917, he decided to form a Potash Production Branch of the Ministry, with Mr. Esslemont as Controller,[1] and Mr. Ransford as Deputy Controller. The branch was to be responsible for dealing with all matters relating to the control, importation, home production, and distribution of all compounds containing potassium, and was to be under the general supervision of the Director-General of the American and Transport Department.

Mr. Chance's proposals were referred to the Advisory Committee, which drew up a report to the effect that, in addition to the large requirements of potash for use as manure, various compounds were of great importance to a number of industries[2]; that the minimum yearly demand would be some 50,000 tons; that Mr. Chance's scheme offered the best and most speedy method of obtaining potash in this country; that the best way of utilising his offer was for the Government to take over the manufacture, at any rate during war-time, using the company as their agents and managers; that until experience should show that Mr. Chance's process had no deleterious effect on the linings of blast furnaces, the process should be limited to five furnaces for six months; that the prices to be paid to the blast furnace owners for their dust should be limited; that the maximum price for potash fertiliser should also be limited, and that arrangements should be made for supplying refined potash compounds to the Government.

Meanwhile the British Potash Company, Ltd., had been formed to acquire and work Mr. Chance's invention, the principal shareholders being the British Cyanides Company, Ltd., the North Lincolnshire Iron Company, at whose furnaces the experiments had been made, and John Lysaght, Ltd., who owned furnaces in close proximity to those of the North Lincolnshire Iron Company.

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[1] General Memorandum No. 10, 8 June, 1917.
[2] See diagram filed in Hist. Rec./H/1930/1, showing the chief industrial uses of the various potash compounds.

III. Agreement with the British Potash Company.

After prolonged negotiations an agreement was entered into between the Minister and the British Potash Company (18 December, 1917) on the following lines:—

The company undertook to increase its nominal capital to the sum of £100,000, of which the Minister was to take one-half. The Minister agreed to advance to the company loans up to £200,000 for the purposes of its undertaking, such loans to carry interest at the rate of 1 per cent. over bank rate, with a minimum of 5 per cent., and to be secured, if required by the Minister, by the issue of debentures.

Mr. Esslemont was to be a Government Representative and *ex-officio* Director, with an absolute right of veto upon all the decisions of the Board of Directors, which was to include two other directors nominated by the Minister.

The dividends on the shares were to be limited to 6 per cent. per annum until such time as a reserve fund of £100,000 had been created and all advances made by the Minister had been repaid. Of the surplus profits, after the payment of 6 per cent., one moiety was to go towards the repayment of the advances and the other moiety to the creation of this reserve fund. Thereafter the amount of the dividend in any year was not to exceed the aggregate of £1 in respect of each ton of fertiliser produced and £2 in respect of each ton of commercial carbonate or caustic, with the proviso that the sums of £1 and £2 respectively might be varied slightly as the cost of manufacture varied.

The Minister also undertook to pay on behalf of the company any excess profits duty for which the company might become liable, and all surplus profits of the company, after payment of the dividend to the ordinary shareholders, were to accrue as dividend on the Government shares. No shares held by either the Minister or the private shareholders were to be disposed of by either party without previous offer of such shares to the other party.

The duty of erecting the factory lay with the company, which was also to enter into agreements with ironmasters whereby the latter should employ the patented process at their furnaces and should deliver the dust to the company, the Minister promising to use his best endeavours to assist the company in entering into such agreements, and to facilitate, so far as was reasonably possible, the erection and equipment of the factory and the provision of the necessary labour. The company also undertook to erect a conversion factory for manufacturing commercial carbonate or caustic from not less than 5,000 tons of the fertiliser per annum, and to deliver to the Minister such compounds as and when required by the Government Representative at a price equal to the cost of manufacture, plus 10 per cent. thereon,

or to the current market price, whichever should be the lower. The company also agreed to procure the British Cyanides Company to enter into an agreement whereby the latter company should undertake to manufacture from the commercial carbonate or caustic supplied to the Minister (but to the extent of not more than 1,500 tons of carbonate or the equivalent amount of caustic) pure carbonate, yellow prussiate, red prussiate, and permanganate of potash.

IV. The Potash Factory, Oldbury.

The erection of the potash factory, which was built on a site adjoining Rood End and Langley Green Station, on the Great Western Railway, near Oldbury, Birmingham, was started in the summer of 1917, and manufacturing operations began at the end of March, 1918. It was designed for a yearly output of 15,000 tons of muriate of potash of 80 per cent. strength, and provision was made for raising the output to 25,000 tons per annum. The engineering details were worked out by the technical staff of the British Cyanides Company, Ltd., and the British Potash Company, Ltd., and the factory was built under the supervision of and with the help of the Potash Production Branch.

The object of the factory was the manufacture of 80 per cent. muriate of potash from blast-furnace dust derived from gas-cleaning plants working in conjunction with blast furnaces in which the salt process was used, and a brief account of the processes employed is given in Appendix VI. Up to November, 1918, blast-furnace dust had been received from three firms only, viz., the North Lincolnshire Iron Works, Palmer's Shipbuilding and Iron Company, and the Ebbw Vale Iron and Steel Company, but as gas-cleaning plants were completed at other furnace works and the salt process was adopted, it was expected that increased supplies of blast-furnace dust would go forward to the factory.[1]

As it was at first intended that the factory should be a government factory, it was known as H.M. Potash Factory, but when the agreement between the company and the Government was signed this title was abandoned. The fact that the factory had become known as a government factory, however, proved useful, as the letters "H.M." carried considerable weight with recalcitrant contractors. The British Potash Company were appointed managers in the erection of the factory, and board meetings were held weekly in the branch, where matters affecting the factory were considered. At these meetings weekly progress reports from the factory management were discussed and lines of action determined thereon. Orders were submitted by the management to the Board, on whose authority the proposed expenditure was sanctioned. At one time, when the constructional work seemed to be lagging, a resident Government engineer was installed at Oldbury, to keep the branch in touch with the Oldbury staff of the Potash Company. Branch inspectors followed up contractors

[1] Photographs of the factory are filed in Hist. Rec./H/1930/1.

and sub-contractors in connection with delivery of plant, etc., and their reports were sent weekly to Oldbury for comment by the company's engineers.

There were all the usual difficulties. Priority certificates had to be fought for, schemes had to be piloted through the Munitions Works Board, labour difficulties incessantly arose owing to the activities of recruiting sergeants against whose claims men had to be protected, and, above all, most of the materials used, from tar to steel plates, were controlled. Railway transport gave a great deal of difficulty, until it was arranged, through the Munitions Inland Transport Department, that rapid transit labels should be issued for practically all material used in the construction and equipment of the factory.

Having regard to the fact that the factory was being built at a time when aeroplane factories and ship constructional work were of overwhelming importance, its completion in nine months was a fairly good achievement. The issue of priority certificates was slow, and often the whole piece of plant, such as a locomotive or an exhaust fan, would be held up through the non-delivery of a few tubes or a ball-bearing. When the factory started running there were, of course, the usual difficulties attendant upon the inauguration of new chemical processes, the chief difficulty being in connection with the vacuum system of the Kestner plant.

The output of the factory steadily increased. During 1918 (from March to the end of December) 840 tons odd of 80 per cent. muriate were made, and from the beginning of 1919 to 31 May, 1919, about 880 tons; thus the total factory output up to the end of May, 1919, was about 1,700 tons of standard fertiliser, and the British Potash Company confidently expected this output to increase steadily.

By November, 1918, eight blast furnaces had been equipped with gas-cleaning plant; 33 additional plants were being constructed, and 22 more were projected. The work, however, was being done on a low priority.

Of the 63 plants mentioned above, 57 were of the Halberg-Beth type of mechanical filter, which is admittedly costly both in construction and in operation, while the remaining six were electrical precipitation plants. Plants of this type had not so far been employed in cleaning the gases of blast furnaces, though they had already been utilised in this country for precipitating dust and fumes of various types, while in the United States they were constantly employed for the precipitation of dust from the gases issuing from Portland cement kilns, a considerable quantity of potash being recovered by this means. These electrical plants were somewhat less costly in construction and considerably less costly in operation than the Halberg-Beth plants, and it was believed by many persons competent to judge that electrical precipitation would prove to be the best method of separating dust from gases, not only in blast furnaces but in many other industries.

V. Negotiations with the Board of Agriculture.

It was necessary from the beginning to work in conjunction with the Board of Agriculture, since their demands for potash were as urgent and imperative a national call as any other, and in amount by far the largest. On 30 May, 1917, in a letter to the Board of Agriculture, the Ministry suggested, with reference to the proposed agreement with the British Potash Company, Ltd.,[1] that the Board of Agriculture should share with the Ministry of Munitions any possible monetary loss involved should the furnaces be put out of action by the use of the Chance process, and further that the Board of Agriculture should guarantee to take the whole of the output of potash with the exception of the comparatively small quantity required for the manufacture of optical munitions. The Board of Agriculture, however, was unable to accept responsibility on these lines, and suggested that the proposition should be reconsidered by Dr. Addison on its merits as a post-war measure for establishing a British potash industry, which would make this country independent of German supplies. At the same time, Mr. Prothero requested Dr. Addison to take immediate steps for the control of the entire output of raw blast-furnace dust, which, on account of the potash it contained, was in itself a useful fertiliser. To these suggestions Dr. Addison agreed in effect. It was suggested, however, that the Board of Agriculture should accept responsibility for the purchase of definite quantities of potash fertiliser, and on 20 July, 1917, the Food Production Department of the Board of Agriculture agreed to take the following amounts at the following prices :—

(*a*) All production up to 31 March, 1918, at a price to be settled later, but which it was anticipated would not be substantially above £17 10s. per ton.

(*b*) Such quantity not exceeding 10,000 tons as should be produced between 1 April, 1918, and 31 March, 1919, at £17 10s. per ton.

(*c*) A quantity up to 15,000 tons between 1 April, 1919, and 31 March, 1920, at £14 per ton.

(*d*) A quantity not exceeding 10,000 tons between 1 April, 1920, and 31 December, 1920, at £14 per ton.

The fertiliser was to be delivered by the British Potash Company in bags on the railway siding at Oldbury and facilities were to be arranged for the co-operation of the Food Production Department with the Potash Company in marketing the product.

Under the Blast-Furnace Dust Control Order, published in August, 1917, the Food Production Department arranged for the distribution of such dusts as might be suitable for use as a potash fertiliser directly as collected at the ironworks, while the Ministry arranged for licensing dealings in the material.

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[1] See above, p. 75.

In March, 1918, the Food Production Department was making arrangements for issuing an order and establishing a distribution scheme for other fertilisers, and was anxious to fix new unit prices for compound fertilisers of which potash was an ingredient. The department accordingly desired to know the probable quantity of potash which could be supplied by the British Potash Company during the year. Unfortunately, the conditions of manufacture generally throughout the country had proved so difficult that, in spite of the utmost endeavours of the company and of the Ministry, it was found impossible to start working the factory at Oldbury until early in March, 1918, and then only on a very small scale. Beyond this, there was the further difficulty that the gas-cleaning plants at the various blast furnaces throughout the country to supply the dusts which formed the raw material of the factory had not yet been erected. It was not, therefore, possible to give a reliable estimate of output or of price at that time, since the price, which depended chiefly on the output, in its turn depended on the supply of raw material.

It became increasingly obvious that the British Potash Company would be unable to carry out its obligations. The cost of production, as frequently happens in new industries, turned out to be very much higher than had been expected, and until a certain amount had been manufactured it was impossible to determine the cost of production on a large scale. The new Compound Fertiliser Order[1] of the Food Production Department and the Ministry of Munitions (4 June, 1918), therefore, was drafted on the assumption that none of the Oldbury potash would be used in compound fertilisers, but that it would be sold for direct application to the land on specified crops. A sample of the manufactured product was sent to the Food Production Department in order that experiments might be made with reference to its suitability as a fertiliser, especially in view of the fact that the first specimens contained an accidental impurity of 1·35 per cent. of prussiate of potash. It was examined at the Rothamsted Laboratory under the direction of Dr. Russell, and the material proved fully as satisfactory as pure pre-war potash salts. In the circumstances, the Food Production Department desired to take over the output of the Oldbury factory.

The Potash Production Branch suggested that the first 2,500 tons should be supplied to the Food Production Department at a price of £22 10s., the next 2,500 tons at a price of £20, and any output beyond this at £17 10s. Even at these prices the company would be selling at a loss, but as the Government had taken half the shares and advanced money to the company, this suggestion was considered not unreasonable. Sir Ernest Moir (Ministry Member of Council under whose administration the Potash Branch came) did not think, however, that the company could be forced to sell fertiliser to the Board of Agriculture at a loss of £5 10s. per ton, Mr. Chance having stated that the then cost of production was £28 per ton. Mr. Chance made an

[1] See Appendix I.

alternative suggestion, viz.: that he would supply 1,000 tons of muriate of potash to the Board at £30 per ton, and that, subject to the supply of this amount, the British Potash Company should be at liberty to sell the balance of their output on the open market at whatever price it might fetch.

Some little time elapsed during which the Board of Agriculture was considering this offer, and meanwhile the accumulation of stock at the potash factory began to interfere seriously with production, and relief was found by supplying the needs of Scotland and Ireland at prices to be afterwards fixed. In September, 1918, the Food Production Department agreed to take the whole of the potash produced at the factory up to 31 May, 1919. Two-thirds of the output were to be taken at the price of £30 per ton for sale to farmers, the remaining one-third was to be taken at £50 per ton for sale to fertiliser makers, for inclusion in potato or other manures. The Board of Agriculture proposed that the agreement should be subject to the following provisions :—

(*a*) That the Ministry should allocate such part of the factory output as it considered necessary to the optical glass industry and the manufacture of refined potash compounds before supplying agricultural needs ;

(*b*) that the Ministry should provide for a costing investigation of the accounts of the British Potash Company ;

(*c*) that in the event of the price determined by costing being less than the actual sums paid by the Food Production Department, the difference should be refunded to the Department.

The Potash Production Branch was unable to undertake that any money should be refunded from the company to the Food Production Department, but promised that a close watch should be kept upon the profits of the Potash Company ; to this the Food Production Department agreed, and the arrangements were accordingly carried out on those lines until the end of May, 1919. The amount of potash thus acquired by the Food Production Department was approximately 1,000 tons of muriate of potash of 80 per cent. strength.

VI. The Elimination of the Government Holding in the British Potash Company.

The position of the Government as principal shareholder in the British Potash Company was the subject of much adverse criticism. There is also evidence of considerable friction between the Potash Company and the Potash Production Branch of the Ministry, and between the former and the General Electric Company, which was taking over the manufacture of gas-cleaning plant from Frasers and Chalmers, Ltd. A licence for working the Halberg-Beth patents had been vested in the Ministry, and the General Electric Company

believed that the Halberg-Beth plant, though suited for gas-cleaning, was not suited for collecting potash-bearing dusts. Moreover, the British Potash Company thought that they were responsible for the erection of gas-cleaning plants, whereas the Potash Production Branch took the view that it was a Ministry responsibility. This unsatisfactory state of affairs was complicated still further by friction between the British Potash Company and the owners of blast furnaces.

From 9 July, 1917, onwards the Ministry was negotiating with the various parties with a view to putting matters on a sounder footing. The negotiations were complicated and protracted,[1] and it was not until 10 April, 1919, that a scheme for getting rid of the Government holding in the British Potash Company, and for forming a new company (in which the chief ironmasters were the principal shareholders) to take over the Oldbury factory, was worked out. The proposed agreement was on the following lines :—

(1) The Government loan of £50,000 to the Potash Company would be repaid.

(2) The Government shareholding to be bought out at par.

(3) Licences to use the salt process would be granted to blast furnace owners on payment of a royalty.

(4) The Government would give a two-thirds write-down on the cost of 20 Halberg-Beth units and their erection. The new Potash Company would erect 30 Halberg-Beth units, *i.e.*, spread the above two-thirds write-down on 20 units to cover 30.

(5) The Government would give a 50 per cent. depreciation on the cost of the Oldbury factory (which up to November, 1918, amounted to £100,000).

The Treasury, which was approached by Sir Philip Henriques on 16 May, pointed out (26 May) that the depreciation condition was open to grave objection in that it put a charge upon public funds of £50,000, which would be unduly favourable to the private shareholders in the company. They stated that if it were necessary to write down the capital of the company they could find no justification for the imposition of the whole loss on public funds. A compromise was therefore arrived at on the basis of the loss on depreciation being shared between the Government and the private shareholders.

VII. Investigation of other Possible Sources of Potash Supply.

Although the attention of the Potash Production Branch was greatly taken up with the blast-furnace dust scheme and its resultant activities, among which the installation and provision of gas-cleaning plant at different blast furnaces ranked as one of the biggest, other

[1] For a full account of these negotiations see History of Potash Production Branch in Hist. Rec./H/1930/1.

possible sources of potash supply were not neglected. A great deal of activity centred round the possibility of recovering potash from felspar, of which Great Britain is known to have large deposits. A quarry at Runcorn which had been reopened supplied felspar for optical glass, and several schemes for obtaining potash from felspar were examined.[1] The problem was not such an easy one as the extraction of potash from blast-furnace dust, as in felspar the potash is present in an insoluble form, and means had to be devised for releasing it and for rendering useful the residue of the felspar in order to make the process economically sound. Further, owing to the cost of quarrying felspar and the low percentage of potash contained in normal deposits, the cost of potash from this source is high.

Kelp, *i.e.*, the incinerated ash of seaweed, has always been one of our native sources of potash. Around the west coasts of Scotland and Ireland kelp burning has always been a crofter's industry, and most of the chlorate of potash utilised by the match manufacturers during the War was drawn from this source, while a certain amount of potash fertiliser material was distributed locally.[2]

Another possible source of supply from which carbonate of potash is obtainable was suint liquor, *i.e.*, the liquor resulting from the washing of greasy wool. As the biggest wool-producing Empire in the world, it was thought that large quantities of potash should be obtainable from this source, but the final result of elaborate investigations[3] was the conclusion that the total quantity of potash available from suint in England would hardly be sufficient to justify embarking on a manufacturing scheme for treatment of the liquors at a centralised factory. This, however, did not preclude local treatment by individual firms.

Large quantities of potash can also be collected from the fume and dust given out by cement kilns in much the same way as from blast-furnace dust. In both cases the potash is fed into the kiln in the raw material. The heat developed is sufficient to volatilise the potash, which, although constituting only a very small proportion of the charge, becomes available in quantity owing to the enormous mass of material dealt with in the aggregate. During 1918 potash was sold by some cement manufacturers who, before their attention was drawn to the matter by the department, had no idea that a valuable material was theirs for the collecting. In other cases where the collection of the dust was a more difficult matter, schemes were in progress both for increasing the quantity of potash present and for collecting it by the use of vacuum pumps.[4]

In addition, during 1918, many other schemes located both in England and in the Colonies were considered, and samples of potash deposits from India and of alunite from Australia were experimented

[1] For details, see Hist. Rec./H/1930/1.

[2] A full account of the investigations carried on by Prof. Kendrick (of Aberdeen) and others will be found in Hist. Rec./H/1930/1.

[3] These investigations are summarised in Hist. Rec./H/1930/1.

[4] For a detailed account of these schemes see Hist. Rec./H/1930/1.

with. Suggestions of the most varied kind were received, ranging from the use of prickly pears, bracken, and cocoanut husks to the utilisation of flue dust from town refuse destructors. Each one was considered and carefully followed out, practical investigations being conducted if necessary. The outlook in the last months of the war was very hopeful; each month that passed rendered Great Britain more independent of German potash, and more able to disregard Germany's continual threats of holding other nations to ransom on potash.

VIII. Control and Distribution of Potassium Compounds.

Blast-furnace dust being a material immediately available as a source of potash, it was found necessary, in order to safeguard supplies for extraction purposes and as a check upon speculative dealings, to issue an order controlling dealings in this material. The Blast-Furnace Dust Control Order was accordingly brought into force in August, 1917.

Under this order no person could buy, sell, deal in, or dispose of any blast-furnace dust except under and in accordance with the terms of a licence issued by the Controller of Potash Production, and no person could treat any such dust for the extraction of any component part thereof except under licence. The blast-furnace dust was defined as dust deposited or otherwise derived from the gases of any furnace used for treating ores for the production of iron or any of its alloys.

On 8 February, 1918, in order to further the production of flax for aeroplanes, a general licence for the purchase of blast-furnace dust under the above order was issued, which allowed the purchase of blast-furnace dusts containing potash to an amount exceeding 13 per cent., expressed as potassium oxide (K_2O), provided that the dusts so purchased were used wholly by the purchaser for direct and immediate application as a fertiliser to the flax crop in Ireland and to no other crop, and provided that they were purchased from or through an agent prescribed for that purpose by the Irish Department of Agriculture and Technical Instruction.

Under the same general licence the purchase of dusts containing potash to an amount not exceeding 13 per cent. (expressed as potassium oxide) was allowed, provided that the dusts so purchased were wholly used by the purchaser for direct application to the ground as a fertiliser, and provided, of course, that they were purchased from a person licensed to sell. The object of this provision was to facilitate the passage of fertiliser directly to the ground. Its effect was to relieve the actual user of having to apply for licences, as it was recognised that any such formality as that of applying for a licence would tend to dissuade farmers and others from using the controlled material. The Blast-Furnace Dust Control Order was suspended as from 30 April, 1919.

As the stocks of potash in the country at the beginning of the War gradually became used up, and the imports from Russia, Canada and other sources diminished, owing to shipping and other difficulties, the prices of all potassium compounds mounted steadily and in some cases reached extremely high figures.[1]

In order to prevent further inflation of prices and to conserve available supplies, it was decided to control dealings in potash, and the Potassium Compounds Control Order was brought into force in October, 1917. The exercise of this control was also considered an essential feature of the scheme for potash production, and a necessary sequence to the order controlling blast-furnace dust.[2]

Investigation of the potash position showed that it was only necessary to control certain basic salts as all other potassium compounds are derived from these. As the supply of nitrate was already being developed by the Explosives Supply Department, four leading compounds only remained and the order was framed accordingly. Under this order, which was still in operation at the end of May, 1919, no person might purchase, offer to purchase, or take delivery of caustic potash, chloride or muriate of potash, carbonate of potash or sulphate of potash, whether in a pure or in a commercial form, or any material (other than blast-furnace dust) of which more than 10 per cent. consisted of any one or more of the above, except under and in accordance with the terms of a licence issued by the Controller of Potash Production. The order also provided that no one might sell, offer to sell, supply or deliver any of the above compounds to any person not holding a licence. It was provided that no licence should be required :

(*a*) By the Admiralty or War Office.

(*b*) By any person for the purchase and delivery of potassium compounds in quantities not exceeding in weight an aggregate of 3 lb. avoirdupois during any one calendar month.

The Blast-Furnace Dust Order included a dual licensing procedure, inasmuch as both purchaser and seller must be licensed. This method gave an absolute check on each transaction, but as it was found to entail a great deal of labour in the matter of branch records, when the Potassium Compounds Order was made, it was provided that the seller only should be licensed. The free traffic in amounts up to 3 lbs. per month was allowed in order to exempt doctors' and photographers' purchases and retail transactions by the general public.

Both orders provided that all persons holding stocks of blast-furnace dust or potassium compounds, or manufacturing, producing, buying, selling or otherwise dealing in these materials, should furnish the returns required of them at the times stated.[3]

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[1] Chloride of potash, for instance, which sold at £9 5s. per ton before the War, cost £60 per ton in September, 1917. C.R.V/Gen./2054.

[2] See Appendix I.

[3] The leading forms which have been used in administering the orders are filed in HIST. REC./H/1930/1.

Shortly after the Potassium Compounds Order came into operation, it became evident that the 3-lb. limit for purchase without licence was too low. Thus, many hospitals ordered 7 lbs. to 14 lbs. of carbonate of potash at a time, and frequently in circumstances which would not admit of delay in obtaining licences. As a result of a deputation from representatives of the wholesale druggists, a general licence for the purchase of potassium compounds for medicinal purposes was issued on 7 December, 1917. Under this the Controller of Potash Production licensed the purchase by any person of potassium compounds coming within the terms of the order, notwithstanding that such purchases might exceed an aggregate of 3 lbs. per month, provided that the compounds so purchased were used solely in British pharmacopœia form, or in British pharmacopœia preparations for purely medicinal purposes.

In February, 1918, a further general licence was issued authorising the purchase of potassium compounds covered by the order in quantities not exceeding in weight an aggregate of three tons during one calendar month, provided that the compounds so purchased were used by the purchaser for direct application to the ground as a fertiliser. The object of this general licence was the same as that of the general licence made concurrently under the Blast-Furnace Dust Order, viz., the removal of formalities which impeded the use of fertiliser material. On 14 March an order, entitled the Potassium Compounds (Partial Suspension) Order, 1919, was issued, suspending the order in so far as it relates to kelp.

The figures obtained from the monthly returns made under these orders showed what stocks of potash were in the country, and the Ministry was accordingly always in a position to license available stocks to the best advantage. In allocating supplies to various uses a system of priority was observed according to the national importance of the purpose for which the potash was required.

In the case of carbonate of potash, manufacturers of optical glass for war munitions came first on the list, and during the whole period of control they received ample supplies. Normal supplies of carbonate were also allowed for medicinal purposes, but it had to be rationed out to most of the other users. Certain industries, such as cocoa and soap manufacture, were looked upon as being more or less essential, and were consequently high on the priority list. The latter was of particular importance, as glycerine, a valuable material for explosives, is obtained as a by-product in the manufacture. The less important industries were allocated supplies in accordance with available stocks.

Applications for licence to purchase caustic potash had to be carefully scrutinised, and the quantities cut down to the absolute minimum, as this material, in all its forms, was scarce from the beginning, and could only be allowed in very meagre quantities even to the most essential industries. Preferential treatment was, as far as possible, given to the dye industry, in view of the fact that it was wholly a German industry before the war.

The supplies of sulphate and muriate of potash, which are principally used for fertilisers, were only sufficient to meet a fraction of the demand. Small quantities were allowed for industrial purposes when they were considered absolutely essential, but the bulk of these materials were deflected to use as fertilisers, and as far as possible to the flax and potato crops, which give larger returns for an application of potash than any other crop. The flax crop was especially important, as there was a great shortage of the flax required for aeroplanes.

At first there was considerable difficulty in estimating the need for these potash compounds in the industries in which they were used, and firms were asked to endeavour to use substitutes whenever possible. In the majority of cases manufacturers were willing to help, and agreed to use substitutes, such as the equivalent salts of sodium and magnesium, although the results were not so satisfactory. Thus, for example, in the manufacture of soft soap and insecticides, manufacturers were able to carry on without potash by the use of caustic soda and oils, although in neither case was the result entirely satisfactory. In the engineering trade a mixture of carbonate and caustic soda was largely used in place of Montreal and caustic potash. Manufacturers of alums used sulphate of ammonia in place of sulphate of potash as far as possible. After considerable pressure had been brought to bear on producers of Parian and Keene's cements, they were persuaded to use alum with a small admixture of potash in place of sulphate of potash. Again, permanganate, prussiate and bichromate of soda took the place of the potash compounds to a great extent during the war.

IX. Purchase of Potash from Abroad.

The supply of carbonate of potash gave considerable anxiety throughout 1917 and 1918. At the end of 1916 it had become evident that to safeguard supplies of optical glass for munitions it would be necessary to obtain supplies of carbonate of potash. Negotiations were consequently opened up with the Russian Government, and after endless exchanges of cablegrams a contract was entered into with the Central War Industries Committee for 500 tons of waterless carbonate of potash, basis 90 to 92 per cent., at a price of £90 per ton. The first consignment of 300 tons was shipped in the s.s. "Errol" on 24 October, 1917, the remainder being shipped by the s.s. "Nyanza" and "Poldennis" on 2 November. Two hundred and fifty tons of the carbonate were sent to the British Cyanides Company, Oldbury, at once, in order that they might commence refining as soon as possible to meet the optical glass-makers' urgent needs for refined material. The remaining 250 tons were put into Government store and forwarded to the Cyanides Company's works when required. The parcels which were shipped on the s.s. "Nyanza" and "Poldennis" were sampled at the port of discharge by a sworn sampler. The 150 tons per s.s. "Errol," which went direct to the Cyanides Company's works, were sampled by that company, and the 250 tons in Government store were dealt with by a sworn sampler appointed by the Potash Production Branch.

An arrangement had been made with the British Cyanides Company under which they bought the Russian carbonate from the Government in successive parcels of 50 tons at a price of £105 per ton net, which was the cost of the delivered material to the Government; they stored and refined it, and were to sell it to glass manufacturers at £150 per ton and to druggists at £175 per ton, in quantities determined by the Potash Production Branch.

It was at first agreed that the carbonate should be reserved for glassmakers and druggists only, but when the caustic potash situation became acute the Cyanides Company was asked to causticise 50 tons of carbonate in order to meet the requirements of dye manufacturers.

The Government purchase of Russian carbonate saved the situation so far as glass and medicinal requirements were concerned, but there was a period at the end of 1917 when other users had to go very short of this commodity. It was then that Messrs. J. Bennet Lawes and Company, chemical manufacturers, Millwall, came to the Ministry, and proposed taking up the manufacture of carbonate from nitrate of potash. The Ministry gave this firm every assistance, especially in obtaining raw material through the Explosives Supply Department, and in a comparatively short time appreciable quantities were being turned out. As the firm had considerable trouble with their plant, and had only reached the smooth running stage when the price of carbonate dropped, it is doubtful whether they made money out of the venture, but their services were patriotically given and helped to meet a difficult position.

Carbonate of potash was also made from nitrate of potash in India, and by arrangement with the Ministry of Shipping 50 tons of shipping space was allocated to carbonate from Calcutta each month. While this arrangement was in force 500 tons were imported from India, which relieved the position considerably. Freight was also obtained to bring consignments of carbonate from New York and Archangel.

Caustic potash was also in short supply, and as has already been mentioned, it was at one time necessary to instruct the British Cyanides Company to convert part of the Russian carbonate into caustic in order that certain industries, especially dye manufacture, could carry on until caustic from the muriate extracted from blast-furnace dust was available. One or two firms were able to purchase two or three small parcels of caustic in America, and this comprised the total imports of this material. The quantities which were afterwards turned out by the Castner Kellner Company on behalf of the British Potash Company did a little, although not much, to help the situation, while Messrs. Forbes, Abbot and Lennard, and later the Astra Chemical Company, produced small quantities of liquid caustic from carbonate, which went to the manufacture of soft soap required for ship launching purposes. Finally, the United Alkali Company began making caustic potash from muriate by the electrolytic method, and it was anticipated that this process would be developed, and that Great Britain would soon be independent of Germany for supplies of caustic.

Caustic potash sticks of a quality suitable for analytical chemical work had never been made in this country, as complete reliance had been placed on imported material from Germany and Sweden. The consumption of this material is not great, but in the early part of 1918 stocks, which had been considerable, began to run out, and, as importation from Sweden was prohibited, supplies were rationed out in the smallest possible quantities, and the United Alkali Company were asked by the Potash Production Branch to consider the manufacture of caustic sticks. They put some of their best chemists on the work, and in a comparatively short time produced excellent laboratory samples of the material. To turn out the commodity in quantity was the next step, and the necessity for obtaining a large gold-lined pot in which to fuse the caustic, and silver moulds for forming the sticks, delayed the output for some considerable time. With the assistance of the branch these difficulties were overcome. Meanwhile, in order to tide over the emergency, a ton of stick caustic was imported from Sweden.

Little could be done to augment the supplies of sulphate and muriate of potash, as, with the exception of the quantities obtained from kelp and tartaric acid manufacture, where sulphate is a by-product, the only source of supply was the extraction of small quantities from blast-furnace dust. Small quantities of muriate were imported from Abyssinia and sulphate from India, but these were intermittent shipments and could not be relied upon.

Wherever possible the Ministry helped those firms who were putting down plants for the manufacture or extraction of these compounds. Messrs. Lankshear, Wickstead and Company and John Bennett Lawes, Ltd., were helped in obtaining plant for sulphate recovery from tartaric acid effluents, and quite a large plant was put down at the works of the Workington Iron and Steel Company at Moss Bay by the Oldside Chemical Company for the manufacture of sulphate from blast-furnace dust. Messrs. E. P. Davis & Co., of the Bennerley Furnaces, Ilkeston, also ran a large plant for extraction of muriate from blast-furnace dust.

Help was also given to several firms who took up experimentally the manufacture of permanganate and other salts of potash. Some of these war-time efforts will undoubtedly perish with the resumption of more normal conditions, but some will survive.

The total quantities of material sold under the Potassium Compounds Control Order up to May, 1919, were as follows :—

I. Total sales under specific licences—

Potassium carbonate	...	2,434 tons.
Caustic potash ...	...	173 „
Potassium chloride ...	...	3,169 „
„ sulphate ...	...	6,566 „
Montreal potash ...	...	34 „

II. Sales in quantities under 3 lb.—
Total weight of all compounds 5½ tons.

III. Sales of potassium compounds for medicinal purposes—

Potassium carbonate	...	17½ tons.
Caustic potash ...	...	4½ „
Potassium sulphate ...	...	34½ „
„ chloride ...	...	1½ cwts.

IV. Sales of potassium compounds for use as fertiliser directly on the ground by purchaser—

Total of all compounds	...	452 tons.

The number of licences issued by the branch to cover the above transactions was 5,694.

X. The Distribution of Blast-Furnace Dust.

In order that speculation in blast-furnace dust might be limited, and the dust rendered available to farmers at reasonable cost, a scheme of distribution through definite channels was arranged in conjunction with the Food Production Department of the Board of Agriculture. Under this scheme dust was delivered in standard grades at fixed prices depending on the potash content.

Eleven firms, who were selected as collecting agents by the Food Production Department, were licensed to purchase blast-furnace dust from furnace-owners at their own terms and to sell it at agreed prices in specific grades to approved selling agents of the department, of whom there were about 400. These agents, in turn, were licensed by the Potash Production Branch to sell the material to farmers at fixed rates.[1]

By this scheme, which worked smoothly and well, many thousands of tons of potash-bearing dust were directed on to the land in circumstances which protected the farmer from exploitation and minimised the formalities in respect of licensing procedure. The agents were licensed for the fertiliser season and the consumers were licensed by the general licence authorising the purchase of dust for direct use upon the ground.

Owing to a change in the method of keeping the returns in the branch made after the Blast-Furnace Dust Order had been in operation for some time, it is not possible to summarise the total quantities of dust which were handled under the control. But the following figures for the period January till December, 1918, will give a sufficient indication:—

Sales to approved fertiliser agents	...	22,480 tons.
„ directly to farmers and the like	...	3,435 „
„ to others than approved agents and farmers...	...	2,938 „
Total ...	...	28,853 tons.

The value of this material was approximately £102,000.

[1] The forms of licence are filed in HIST. REC./H/1930/1.

The quantity of dust treated for the extraction of potash content during the above period was 5,964 tons, and the total number of licences issued by the branch under the Blast-Furnace Dust Order was 4,625.

Import and export regulations have been a matter requiring constant and close attention. The Ministry had to deal with conflicting interests, inasmuch as traders who were desirous of continuing their pre-war business in foreign markets were pressing to be allowed to export potash material, while, on the other hand, the total stocks in the country were so small that export had to be restricted. Applications for licence to export were referred to the branch by the War Trade Department and as a result export was kept down to a minimum, and licences for export were only given when the material was to be used for medical purposes or for chemical analysis, or in the case of applications to export upon which the supplies of important raw materials or munitions depended.

During the final months of the war and during the period of November, 1918, to May, 1919, it was found possible to allow increasing quantities of carbonate, muriate and sulphate to go out of the country. Imports of potash during the war period, of course, were free and, as has been shown above, were encouraged in every way.[1]

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[1] An account of the agreement to buy German potash, and of the way in which this conflicted with French interests in the recovered Alsace potash deposits, is given in HIST. REC./H'1930/1.

CHAPTER V.

LABOUR CONDITIONS.

I. The Enlistment of Skilled Men.

The labour problems of the department ranged from the settling of a strike to the certifying that a workman was engaged on work of national importance so that he could obtain a season ticket to his work.

Much of the work was of an advisory character. The department was called upon to advise the Ministry of National Service with regard to questions of exemption in the glass trade, and the Labour Supply Department on similar questions in the instrument-making trades; it advised the Home Office on hours of labour for women in the glass trades, the Ministry of Reconstruction on the formation of Industrial Councils, the Ministry of Labour on similar questions and on strikes, while it undertook training of disabled soldiers in the Optical Munitions Training School.

One of the department's first difficulties was the great lack of skilled labour in the scientific instrument making trade. Some of the men originally in the trade before the outbreak of war had enlisted, others wanted to enlist, and it was subsequently necessary to secure the return from the Army of men useful in the production of optical munitions, and, later, scientific glassware.

In the autumn of 1915 most of the men engaged on munitions work in the instrument making trades were protected from recruiting by the issue of War Service Badges, as a rule on the recommendation of the Optical Munitions Department. After the passing of the Military Service Act and the conversion of the badge certificate into a certificate of exemption, the duty of revising periodically the list of men possessing badges was entrusted to the department's progress inspectors, on account of the special technical questions involved. The revision started in May, 1916, and badges were withdrawn from men who were not employed for 75 per cent. of their time on the production of optical munitions, and men who could easily be replaced by women. In a few instances, when it was found that employers were more concerned to keep their private trade than to do Government work, they were compelled to undertake more work for the department by the threat to debadge their men. From the outset the Optical Munitions Department worked in close touch with the badge section of the Labour Supply Department, and its recommendations were readily accepted.

The adoption of the Trade Card scheme (18 November, 1916) led to difficulties and it rapidly became unworkable. It was also unsatisfactory from the military standpoint, and it gave rise to further labour unrest. The trade unions exempted too many men; cards

were given to men who could be replaced by women, and there were inequalities in judging who was skilled and who was not. Some unions included in the scheme made use of their privilege to recruit men from unions which were excluded, and some secretaries even went the length of making the granting of cards conditional on payment of arrears of subscription. The Optical Munitions Department found that neither men engaged on the actual manufacture of optical glass nor on glassware, such as thermometers, were covered, and was compelled to make special efforts and special arrangements to keep the essential men.

At the end of 1916 the unskilled and semi-skilled men of twenty-two years of age who were not covered by the scheme were being called up whether substitution could be effected or not, and it seemed probable that the age would shortly be raised to thirty. In order to be well in advance of this development, the department put great pressure on manufacturers to dilute.

A new scheme of exemption, based partly on occupation and partly on age, was substituted for both trade cards and badges at the beginning of May, 1917, the Schedule of Protected Occupations having been published on 28 April, 1917. The interests of the optical munitions trades were protected in this Schedule under certain headings, but difficulties arose in connection with a number of men who did not clearly come under any of these definite headings; for example, ebonite workers, emery workers, and pearl workers engaged in the manufacture of pearl dials for compasses, etc., but workmen in most of the glass trades which did not fall within the scope of munitions work were covered by the Certified Occupations scheme in the Schedule dated 23 June, 1917.

When at the beginning of 1918 it became clear that revision of both schedules would require to be carried out in order to provide the men necessary for the Army, there were several discussions with Trade Societies and Employers' Federations regarding probable changes.

The optical munition manufacturers, who had by this time carried out a large amount of dilution, and who had accordingly realised its possibilities, were not as much afraid of the revision of the schedules as the glassware manufacturers, who were chiefly engaged in manufacture on a small scale and who had little initiative and little capital. The idea that all young men under twenty-four years of age might be called up, irrespective of their occupation, threw many of them into a state of consternation. Of all the contractors for the department, those who were engaged on clinical thermometers were the most unwilling to dilute. Only one firm, A. C. Cossor, Ltd., really faced the problem and made a success of dilution. The majority of the manufacturers thought they had done well if they introduced women on dividing alone, without extending the employment of women to actual glass-blowing operations, for which they had been proved eminently capable by such firms as Hyposol, Ltd., and E. Williams & Co.

In the revised Schedule of Protected Occupations, published on 1 February, in which there was a " clean cut " above the age of twenty-three, the glasshouse pot-maker was protected for the first time. Since experience had shown that women could be employed on roughing operations in optical munitions, lens or prism roughers were eligible for service up to the age of thirty-two. The " clean cut," however, was not put into operation up to its fullest limits. But the Schedule gave the Munitions Area Dilution Officer, who administered it, much wider discretion as to the ages of the men whom he called up to supply the quota of men required for the Army.

At the end of March, 1918, when the Germans were making victorious progress in France, it became evident that a very serious demand on the man-power at home was necessary to meet the requirements of the Army. The order issued on 9 April, 1918, withdrawing protection from certain types of men formerly covered by the Certified Occupations List scarcely touched the optical munitions trades, merely withdrawing exemption from glass bevellers, embossers, silverers, etchers, engravers, and stainers, who were chiefly engaged in the luxury trades. In the middle of April, 1918, a proclamation was issued declaring that a national emergency had arisen, and that all certificates of exemption granted or renewed to men in Grades 1 and 2, born in the years 1895 to 1899, should be withdrawn. At the same time all soldiers who had been released from the colours for munitions work and who were fit for general service were recalled. As it was realised that a few of these men might be regarded as " pivotal on war work of the more urgent character," and that in some cases the loss of certain men would so derange or unbalance the establishment of firms as to affect very seriously work of special importance, firms were invited on 28 April to make special application for such men.

This raised in an acute form a controversy as to what was a " pivotal man." The optical instrument manufacturers had very different views on this point, but it was made quite clear that very few claims would be supported by the Optical Munitions Department, and that manufacturers would do well only to submit first-class cases. As a proof of the spirit in which British optical instrument manufacturers faced the problem, it is worthy of mention that Messrs. R. and J. Beck, who stood to lose 120 men, only applied for two pivotal men ; and Messrs. Ross, Ltd., with about an equal loss of men, applied for none. It was estimated that a 15 per cent. drop in output might be expected, but the larger firms very quickly made up the loss by extending dilution, and before long Messrs. Beck were turning out more dial sights than before. The only store on which a continued drop in output occurred was certain Admiralty telescopes, and when the position became easier it became necessary to endeavour to secure the return of some of these men.

By 20 June, 1918, it had become evident that the arrangement by which " pivotal " men, born in 1898 and 1899, in Grade 1 should be exempted, had proved unworkable. The authorities found it

difficult to determine what men under twenty-one were really "pivotal," and the War Cabinet decided on an absolute "clean cut," and called up all these men at once, without exception.

The last change in regulations which affected the labour of the Optical Munitions Department during the War was the issue of a new revised list of certified occupations on 26 September, 1918. This list was somewhat different in character from the previous one, in that it granted exemption without distinction as to whether the man was married or single, and simply depended on the man's age and his grade. Grade 3 men had by this time no importance from the military standpoint, so that all the Grade 3 men in optical munition trades were exempted. This list included not only the glass trade, but also the sight-testing opticians, the spectacle makers, and the felspar miners. The conditions on which exemption was granted were arranged with the National Service Department.

The last important step taken by the department to secure labour eligible for military service was taken at the end of September, 1918, with a view to getting back from the Army some 300 young men who had been called up under the "clean cut," in order to produce Admiralty telescopes, the output of which at this time had fallen greatly into arrear. Arrangements for this had not been completed when the Armistice was signed.

II. Labour Supply.

The Optical Munitions Department did relatively little in the way of supplying labour direct to firms engaged on its stores. Occasionally, when workmen visited the department seeking fresh employment, they were directed to the firms who seemed the most likely to require the services of the type they could offer; but, generally speaking, when a demand for labour was received it was referred to the Labour Supply Department to be met either through the Employment Exchanges or else by the transfer from some other firm of a workman who had enrolled as a War Munitions Volunteer. The Employment Exchanges were not successful in supplying labour in the later part of the War, even though the firms were on the priority list with a high degree of priority. Nor were men often transferred from one factory to another, largely because it was difficult to find men who were not required in their own establishments.

To meet the need for labour recourse had to be made to dilution, and in order to render this effective an Optical Munitions Training School was instituted, which did excellent work, especially in teaching manufacturers how dilution could be carried out successfully. Apart from this, however, dilution was preached by the inspectors of the department for two or three years.

Various changes in working conditions were made in the glassware trades by which labour was saved or output increased. American methods of making bottles made considerable headway during the

War; for example, machinery was introduced on a considerable scale in place of hand labour, but, generally speaking, the hand workers objected to the introduction of machines. In some few cases friendly relations between the manufacturers and the men led to agreements regarding the working of machines at the same tank as a hand blower.

Investigaticns as to the best working conditions led to the introduction at Kinghorn of the plan by which three men worked two machines continuously, each man having twenty minutes' rest out of each hour, with the result that output and time-keeping greatly improved.

The restrictions on the employment of women in glass-houses and the opposition of trade unions to their introduction led, in some cases, to older men doing work formerly done by boys. These processes could probably have been done equally well by women or girls, but the older men, in some instances, were thrown out of employment by the breaking up of sets of workmen by enlistment.

III. Alien Labour.

Aliens were employed in all branches of the industries controlled by the department, chiefly Belgians in the optical munitions trades and Dutchmen and uninterned Germans in the glass trades.

In many cases the friendly aliens were subject to military service laws and conventions. The exemption of Belgians rested for a long time in the hands of the Belgian authorities, but friendly aliens were generally subject to a convention by which they either were repatriated for service in their own armies or became subject to English regulations. In the latter case, in several instances their exemption from military service had to be secured.

Full use was made of the services of alien enemies. Several very skilled glass blowers were amongst them, who were employed chiefly in the manufacture of chemical glass required for explosives purposes. A small number were employed on the manufacture of prisms and lenses, and one of these was of considerable importance because he trained women for the manufacture of lenses by very good methods.

Most of these enemy aliens were of sufficiently good character to remain uninterned until about August, 1918, when newspaper agitations for the internment of all enemy aliens was at its height, and Mr. Justice Sankey's Committee was appointed to decide whether they should be interned or not. The department was consulted by this committee, and while it made no special efforts to keep out of internment men who were bottle blowers, it endeavoured to keep out men who were really essential to the continuance of contracts for urgent stores.

IV. Dilution.

In the optical munitions and glassware trades, manufacturers were rather slow to realise that the fundamental principle of dilution

was the increased employment of women, with a view to employing the minimum amount of skilled or unskilled male labour necessary for the work in hand. This meant that skilled men should be confined to work which could not be done efficiently by less skilled labour; that women should be employed on all classes of work which was suitable for them, and that semi-skilled and unskilled male labour should be employed only on such work as was unsuitable for women, but which did not demand skilled workers to be done efficiently.

In many cases firms considered that dilution had been carried out quite satisfactorily if a large number of women were being employed. The managers of these firms failed to see that the employment of large numbers of women did not necessarily constitute good dilution, but only the employment of the minimum amount of skilled and unskilled male labour necessary for carrying out their contracts. In some cases dilution was effected by the employment of boy labour, and this was considered satisfactory in the scientific instrument firms, where the boys would be able to continue the work after the War.

(*a*) Optical Work.

In optical works dilution took place very slowly indeed. In the first place manufacturers had to be convinced that women could do first-class optical work, and, secondly, the intense opposition of the glass-workers had to be overcome.

The Optical Munitions Training School proved the capabilities of women in lens and prism work, but, at the same time, it probably increased the opposition of skilled glass-workers to the introduction of women into optical workshops. Before the War, optical work had been monopolised by a few skilled men, the majority of whom were not of a very high type, and it was not surprising that they should resent the introduction of women on glass-work. Further, lens and prism work had always been regarded as very highly skilled work, which could not be learnt in less than two or three years, and the ease with which women learnt to do certain operations proved that the skill required was not of such a very high order, and this, naturally, did not tend to make the men view the new conditions any more favourably. As a matter of fact, women had been employed on optical work before the War, and had been employed by Messrs. R. & J. Beck for fifty years. Such cases were, however, rare, and not generally known.

When it became evident that the output of optical munitions was being limited by the lack of optics, manufacturers were compelled to consider seriously the question of the introduction of women into the glass shops. Many determined to do so on a large scale. Messrs. Hilger devised special machines and jigs by which skilled work could be done by unskilled women without any preliminary training. Messrs. Watson, realising that it would be impossible to introduce women into their Barnet works without an enormous amount of friction, opened a factory for women glass-workers at East Finchley, and

obtained the release from internment of Bielstein, their former foreman, to teach them. Under his tuition excellent work was done by the women in this factory. Messrs. R. & J. Beck ultimately employed as many as 286 women in their glass factories, but the majority of these were working on optics for the tank periscopes and telescopes, work eminently suitable for beginners, as a high standard was not required.

Many firms, however, experienced difficulty in introducing women, owing to the difficulty in finding suitable women for glass-work, and in training them when they were found. The Training School was of great assistance in such cases, and firms such as Messrs. Dollond and Hughes drew nearly all their glass-workers from this source.

Although a large number of women were eventually employed in glass shops, few firms made as much use of them as they might have done. Some never employed them on roughing, as it was considered either too hard or too dirty for them ; others, again, never employed them on edging for fear that they should spoil finished work, although they could do both these operations well.

Even in cases where women were employed in satisfactory numbers the output was frequently far too low. Many cases of complaints of unsatisfactory work by women had to be investigated, but in the majority of cases it was proved to be due to a determined policy on the part of either the foreman, the men, or both, to prevent the women from doing good work. These men, backed by their union, and realising that the failure of women in one factory would prejudice the general employment of women on glass-work far more than their success in another factory would stimulate their employment, put all kinds of obstacles in their way. In one factory, for instance, a worker had to share her tools with a man, and it was alleged that she put out of curve the tools he had to borrow. In the same factory a woman worker who had done good work was suddenly dismissed for being obliged to spend one whole week in getting her tools up to curve. On investigation, it was found that during her absence on sick leave her tools had been used by a boy just beginning lens grinding, who had put them out of curve, as nearly all beginners do. The foreman, however, argued that he could not possibly have put them out, and dismissed the woman worker for having done so. In another case, the foreman was afraid to give the women any help in their work for fear of the men rising against him. Many other examples could be given to show how many difficulties women employed in glass shops had to contend with. However, much good work was done, and in many cases the output compared favourably with that of the men.

Comparison, of course, is not easy, but a suitable case may be quoted where eye lenses for dial sights were made by both men and women. A girl working three spindles smoothed and polished, on an average, four blocks per day of 8¾ hours. A man on four spindles completed five or six blocks per day of 11 hours. In this case there is little difference in the output per spindle; the balance, if anything, is in favour of the girl. This comparison was made, of course, between the most

highly skilled of the girls and a semi-skilled man. The total output from fifty women for a week of 48 hours was 1,600 polished surfaces. In the majority of cases smoothing had been done by the women in addition to the polishing.

An equally good example is the output from twenty-seven women workers, divided into six roughers, seventeen smoothers and polishers, three edgers, and one balsamer.

The average output per week of 47 hours was :—

135 Prism Binocular O.G.s	.. .. ..	270 lenses
140 ,, ,, Eye Lenses	.. ..	280 ,,
70 ,, ,, Fields	.. ..	70 ,,

making a total of 620 lenses, or 1,240 surfaces.

The highest class of work done by women was the polishing of 2 in. diameter lenses for aerial photography, which were worked by a few women with about two years' experience. This is one of the very few cases in which women workers have been upgraded satisfactorily.

On the process of roughing, the output by quite young girls in some cases exceeded that of the men.

After the Armistice the firms in the optical trade were obliged to dismiss their women workers, many of whom had had over two years' experience, and had acquired a considerable amount of skill. Many of them took up the work with the intention of continuing it after the War, and to help to keep in this country a trade which before the War was practically entirely in the hands of Germany. The dismissal of these workers was caused by the sudden cancelling of contracts for optical instruments, the firms concerned having no definite post-war work on to which they could turn the women workers.

(*b*) Instrument Making.

With regard to instrument making, the chief difficulty was to persuade manufacturers that the only way in which dilution could be carried out satisfactorily was by subdivision of operations. A skilled instrument maker is capable of making an instrument throughout, and therefore it was frequently argued that unskilled or semi-skilled labour could not be used on this type of work. In very many cases when a proper subdivision of operations took place, it was found that the whole instrument could be made by unskilled and semi-skilled labour. Such was the case with the prism binocular, which was later on made almost entirely by women. This subdivision of operations, however, could only be carried to its full extent by firms who had a running contract for one or two instruments, and the placing of contracts for stores in relatively small quantities was a great stumbling-block in the way of increased employment of unskilled or even semi-skilled labour. Some small firms found it almost impossible to dilute, and it would have been unreasonable to urge further dilution when they had only small contracts, each providing at the most only a few months'

work with no definite hope of continuing on that particular type of work. In such cases the reorganisation of labour to make the best use of the skilled men, and to make it possible to introduce or worth while to train women, was impossible.

The percentage of skilled men naturally remained high in firms engaged on experimental work owing to the small amount of repetition work possible, and it would have been advisable to reserve certain firms for experimental work instead of giving them small isolated contracts to be carried out together with work of an experimental type.

When an entirely new type of instrument was undertaken, it proved a good opportunity of introducing women's labour, often in large numbers. For example, one firm making aero-compasses for aircraft started women on these at the beginning of the contract, and trained them to make the compasses throughout and test them without any skilled labour being used except for supervision. In some similar cases, however, firms were most unwilling to introduce women, even for work on a new instrument which was well within their powers. One notable example is that of a firm which undertook to make compasses, and requested the help of the department in getting no less than fifteen men released from the Army for this purpose. They proposed to put men who had been used to capstan lathe work on to assembling compass parts, and had not realised that if a man with no experience in assembling work of any kind could be trained to it, so could female labour. The department helped this firm to introduce women into this work, and in the end the magnetic mirror compass was almost entirely made by them.

In metal work for optical munitions the operations performed by women were similar in character to those done by them in other engineering trades, such as turning, milling, drilling, tapping, screw-making, etc., but on these operations dilution was not as satisfactory in many works as it ought to have been.

Such operations as dividing and engraving, lacquering, sandblasting and painting were done by women in practically all optical munitions firms, and at quite an early stage the suitability of dividing and engraving work for women was recognised. Many assembling, adjusting and testing operations were successfully carried out by women, but a number of more delicate operations could have been entrusted to them. The manager of one firm who wished to introduce women in his factory, but who was extremely doubtful as to how his men would receive them, started one or two on engraving machines. Finding that the women did this work just as well as, if not better than, themselves, the men raised no objection to their gradual introduction on other operations, and finally over twenty were employed on sextant making.

A greater output from women workers would probably have been possible had many managers and foremen realised that machine operations become monotonous after a time, and that monotony tends to lower the output from individual workers. Messrs. Dollond, who

from the beginning made good use of women's labour in the manufacture of prism binoculars, were to be congratulated on training their girls on more than one operation so as to prevent their work becoming monotonous. In the machine shop, for example, the same worker would turn vulcanite eye-cups, do the final truing of field lens cells, and tap bodies. Another would file and finish bodies, file lugs to shape at vice, and also polish eye-cups on a polishing machine.

At the beginning of 1918, out of a total of 1,720 optical glass-workers, one-third were women, and out of a total of 5,389 metal-workers (including turners, fitters, instrument makers, toolmakers, etc.) one-fifth were women. This was the position before the "clean cut" of young men between the ages of 18 and 23 took place, after which the number of women employed increased, bringing the proportion of women optical workers up to about 50 per cent., and of women engaged on instrument making to about 40 per cent.

A process sheet, giving typical examples of the operations in optical munitions making on which women were successfully employed, is given in an Appendix.[1]

(c) GLASSWARE.

In the glassware trades women were generally employed on the more elementary processes only. Out of a total of about 18,000 employees they numbered about one-sixth. The amount of boy labour employed was relatively very high, being about one-half of the total male labour, over 3,000 being employed on the making of bottles and jars.

It was on lamp-blown scientific and medical glassware that women were employed in the largest numbers, for this work, especially the making of medical glass, was readily learnt even by quite young girls.

Investigation into claims for exemptions from military service, especially of thermometer makers, revealed the fact that the Lamp-blown Scientific Glassware Manufacturers' Association was opposed to dilution, the employers stating that women failed because of "(a) lack of interest in their work; (b) irresponsibility and absence of appreciation of accuracy; (c) the extreme uncertainty, women having to leave owing to domestic matters either during training or when they have become efficient." These, however, are difficulties common to every industry, and did not operate more in thermometer making than in any other trade. The greatest difficulty with regard to dilution in thermometer making firms was to persuade manufacturers that six or seven years' apprenticeship was not necessary before a worker could blow the bulbs and make the constriction.

Illustrations of the fact that a long training was unnecessary may be quoted: A youth of 17¾ years of age set up in business for himself as a clinical thermometer tube-maker, and was able to turn out over a gross of tubes per week. Another youth, aged 17, with less than two

[1] See Appendix VII.

years' experience, wished to obtain exemption from military service in order to set up in business with another youth, aged 16, as clinical thermometer tube makers. One firm, employing a large number of girls, trained them to do all the processes involved in making a clinical thermometer. In many cases it was impossible to urge dilution, for small firms had their workshops in very small, badly ventilated garrets, where it would have been impossible to make conditions in any way suitable for women.

Over 1,000 women have been employed in the making of bottles and jars, both by hand and machine, about two-thirds of this number being engaged on hand processes, while of the total number of workers engaged on domestic and fancy glass, such as table glass, ornamental ware, etc., about one-third were women.

The manufacture of articles from molten glass direct from the furnace was for some time considered unsuitable for women, owing to the very high temperatures to which they would be exposed, but by erecting suitable screens to protect them it was made possible for them to work in the glass-house, and they were thereby enabled to produce electric lamp bulbs. An arrangement was made with the Home Office by which the employment of women over 18 years of age in glass-houses was permitted both by day and by night, and, in addition, girls over 16 years of age could be employed by day.

The best piece of glass-work done by a woman was the making of a Röntgen Ray tube and a rectifying valve.

A process sheet giving typical examples of women's work in the various glassware trades is given in an Appendix.[1]

In order to stimulate dilution, exhibitions of women's work were arranged by the Labour Supply Department of the Ministry of Munitions, a section being devoted to exhibits of optical munitions and glassware.

The first was held at the Colonial Institute, Northumberland Avenue, early in 1917. The exhibits of lens and prism work and medical glassware attracted much attention, and many manufacturers expressed surprise at the progress which had been made by women in these trades. Later on, exhibitions were held periodically in the various large industrial centres of England—Manchester, Birmingham, Liverpool, etc.—which were of great value in proving to manufacturers all over England the capabilities of women in many types of industries.

V. Wages.

(a) Optical Munitions.

In 1914, when the War broke out, the standard wage for a skilled engineer or scientific instrument maker was 9d. per hour as a minimum, but at that time an advance was being demanded which was settled shortly after the War began, in October, 1914, by an advance of ¾d. per hour for time workers, and 7½ per cent. on piece-work prices.

[1] See Appendix VII.

During 1915 there was only one change in wages. In April of that year 4s. a week war bonus was given to time workers and 10 per cent. to piece workers.

In 1916, again only one award was made, 3s. a week being given to time workers only in November of that year.

In the meantime the cost of living had risen greatly, and throughout the spring of 1917 it continued to rise rapidly. As the result of an agreement in February between the Engineering Employers' Federation and the unions with which it negotiated, the Committee on Production heard the claims of the engineering and allied trades together at intervals of four months and awarded national advances. These advances were temporary adjustments designed to meet the rise in the cost of living. The result of these regular meetings was a rapid increase in wages, beginning on 28 March with an award of 5s. a week to both time workers and piece workers over eighteen years of age and 2s. 6d. a week to boys, the first payment being made as from the first full pay in April. On 7 September another award of 3s. a week to men and 1s. 6d. to boys as from 1 August was made.

On 13 October, owing to the dissatisfaction of the skilled time workers with the high earnings of unskilled men on piece-work—a result largely of improved methods of production, the fixity of piece-work prices, and the insistence of the skilled worker that everyone doing a skilled man's job should have a skilled man's pay—an order was made by the Minister by which skilled time workers in the engineering trades were granted a bonus of 12½ per cent. on their total earnings (including bonuses) as from 12 October, 1917. This order was not sufficiently definite because there were all degrees of skill, and, moreover, the engineering trades contained many types of skilled artisans, some of whom were included in the order and some not. The agreement by which the unskilled man doing the skilled man's work was to receive the same payment was followed by the extension of the award, on 11 December, to all men engaged on munitions over twenty-one years of age, whether skilled or not, in all the engineering trades. In addition to this advance of 12½ per cent., the Committee on Production, in December, 1917, awarded a further 5s. a week to both piece workers and time workers, and 2s. 6d. to boys as from the beginning of the first full pay in December.

By this time the piece workers were clamouring that they had been unfairly treated by the award of 12½ per cent. to the time workers. With a view to equalising matters, another order was made in January by the Minister, by which a 7½ per cent. war bonus was granted to all piece workers over twenty-one years of age on their total earnings, including bonuses already declared.

In the optical munitions firms, both the men making optical elements of glass and the metal-workers belonged to the same trade union, and the glass-workers felt that they deserved awards as much as the metal-workers. They accordingly made an application to the

Committee on Production to hear their views, and on 26 February the 12½ per cent. bonus to time workers and the 7½ per cent. bonus to piece workers were extended to optical workers as from 1 January, 1918. The custom of the trade had been to give to both optical workers and scientific instrument makers the awards of the Committee on Production, so that there was no reason for refusing them the other awards made to workmen in the same factories.

On 24 July, 1918, the Committee on Production gave a further bonus of 3s. 6d. a week to men and 1s. 9d. to boys as from 10 August. Lastly, an award of the same Committee was made on 9 November, granting a further 5s. to men and 2s. 6d. to boys, to be paid in the week ending 7 December.

It is interesting to note the total effect of all these awards on the wages of the scientific instrument maker and his position as regards total earnings. The normal week in a factory varies from 48 to 50 hours, and overtime is charged at the rate of time and a quarter for the first two hours overtime daily and time and a half for anything over that number of hours. If we take a worker who has a normal 50 hour week, at the minimum rate of 9d. per hour before the War, he would be earning :—

	£	s.	d.	
At Christmas 1914	2	0	7½	per week
,, ,, 1915	2	4	7½	,, ,,
,, ,, 1916	2	7	7½	,, ,,
,, ,, 1917	3	8	2½	,, ,,
,, ,, 1918	3	17	9	,, ,,

But earnings were considerably augmented by working overtime. In the optical munitions trades men did not less than ten hours of overtime a week, for which they were paid time and a quarter with all bonuses in proportion, or nearly £1 a week at the end of the War.

The wages of women employed as optical and scientific instrument makers were regulated by the Ministry under the "women's work" orders,[1] which related to the remuneration of women and girls on munitions work of a class which, prior to the War, was not recognised as men's work in districts where such work was customarily carried on. The first order applied to the women employed in these trades was dated 6 January, 1917. The rates were as follows :—

(1) Time-rates for piece workers and premium bonus workers :—

Workers of 18 years and over	4d.	per hour.
Workers of 17 years and under 18 ..	3½d.	,,
Workers of 16 years and under 17 ..	3d.	,,
Workers of 15 years and under 16 ..	2½d.	,,
Workers of 15 years	2d.	,,

[1] See Vol. V. Part II., Chapters V. and VI.

(2) Workers customarily on time :—

Workers of 18 years and over	4½d. per hour.
Workers of 17 years and under 18 ..	4d. ,,
Workers of 16 years and under 17 ..	3½d. ,,
Workers of 15 years and under 16 ..	3d. ,,
Workers under 15 years	2½d. ,,

The girls were further rated at ½d. per hour less during probationary periods, which in the case of workers of 18 years and over was one month, and that of workers between 16 and 18 two months, and under 16 three months. The piece-work prices were to be such as to enable a woman of ordinary ability to earn at least 33⅓ per cent. over her appropriate time-rate.

This order was applied to women optical workers on the supposition that their employment was not to be temporary, but that they would remain in the optical trade after the War, and were to be regarded as apprentices learning a skilled trade. Women had been employed before the War in small numbers, and at Messrs. R. & J. Beck's they had been employed for about fifty years, chiefly engaged on the production of microscope optics. Their system of payment had differed from that for men, and, generally speaking, in Messrs. Beck's establishment the piece-work rates paid to women had been the same piece-work rates as those paid to apprentices.

The war bonuses applicable to these women were made by Orders of the Minister in every case. Thus on 4 April, 1917, the wages of women over 18 years of age were advanced 1d. per hour on time-work, and of women between 17 and 18 years of age ½d. per hour. Corresponding advances for women on piece-work were ¾d. and ¼d. This order came into operation as from 8 April, 1917. On 31 July, 1917, women over 18 years of age were awarded 2s. 6d. for a full ordinary working week, and girls under 18 years of age 1s. 3d., as from 15 August, 1917. On 7 November, 1917, women over 18 years of age received an addition of 2s. 6d per full ordinary working week, and girls under 18 years of age 1s. 3d., as from the beginning of the first full pay following 19 November, 1917. On 14 January, 1918, women over 18 years of age were given a bonus of 3s. 6d., and girls under 18 years of age 1s. 9d., as from the beginning of the first full pay following 15 December, 1917. Lastly, on 28 August, 1918, women over 18 years of age received an extra 5s. per week, and girls under 18 years of age 2s. 6d. per week, as from 1 September, 1918.

The following represents the wages earned for a 50-hour week by a woman over 18 years of age engaged in optical work as a productive hand at various dates :—

January, 1917	£0	18	9
April, 1917	1	2	11
August, 1917	1	5	5
December, 1917	1	7	11
January, 1918	1	11	5
December, 1918	1	16	5

These were the minimum rates payable, but the Wages Regulation Department did their best to insist that after six months' experience a women should receive at least 7d. per hour, with the appropriate war bonuses. A woman who had reached this figure of 7d. per houi would, under the same circumstances, be receiving £2 2s. 8d. An endeavour also was made to raise these women's wages by the introduction of piece-work systems, and in one or two cases in Messrs. Beck's factory women were actually paid something like 1s. 2d. and 1s. 3d. per hour as total earnings.

During the last few months of the War the Scientific Instrument Makers' Society were rather anxious to find some way of displacing the women, and they had apparently considered that the best method of doing so would be to make the women's work unprofitable to the manufacturer by insisting on the payment of the same piece-work prices to women as to men. The department pointed out that the women could not be regarded as mere "dilutees," and that, consequently, the return to pre-war conditions must carry with it the right of employers to treat the women after the War in the same way as they were accustomed to do in pre-war times, both as to wages and as to choice of employment.

Although there were several cases of labour unrest during the period under review, few of these occurred in connection with wages, and the trouble then was mainly due to the comparison of piece-work rates between different shops in the trade. Piece-work prices at Messrs. Ottway's works, for example, were considerably below those paid by Messrs. Beck for the same work, but the methods adopted for the work were in most cases different, and the comparison of piece-work prices was therefore difficult.

(*b*) GLASSWARE.

In the glass trades, generally speaking, the department had little influence on the wages question. The Ministry did not at any time regulate the wages in these trades, but the general movement of wages followed similar lines to those of munition workers.

The following table gives a comparison of the rates in the flint glass trade in 1914 and at the end of 1918, the rates being for a day of 10½ hours, except in the cases of teazers, furnace minders, and lehr minders, who in 1914 worked a 12-hour shift, whereas in 1918 they worked an 8-hour shift :—

	1914.		1918.		
	s.	d.	s.	d.	
Gaffer or finisher	16	0	22	9	
Servitor or blower	10	8	18	5	
Footmaker or third hand	7	8	14	5	
Teazers, furnace and lehr minder, 12-hour day	30	0	60	0	8-hr. day
Boy helper	2	2	4	0	

These wages applied to all the table glass workers, and to those men engaged in the manufacture of chemical glassware who did not work on unrestricted output piece-work systems. The general custom in the Stourbridge area was that a certain number of articles should be made per turn, nominally six hours, but the tendency of the workman was to stop when the allotted number of articles were made, even after only three hours.

The first attack on this system was made when piece-work rates on an output bonus system were introduced on electric lamp bulbs. It was arranged at a conference, under the chairmanship of Mr. Steven, that this output bonus system should come into operation early in 1918. This arrangement did not last for any length of time, but it led the way, and on 18 March, 1918, a slightly different rate was introduced which appears to have been quite satisfactory to all parties. This in its turn led to the adoption of a similar system for the manufacture of lamp chimneys, an output bonus scheme of piece-work prices being arranged in August, 1918.

The men in this industry who profited most by the War were the tube drawers, especially those who made clinical thermometer tubing. Even as early as the middle of September, 1917, Messrs. Powell stated that seven tube drawers, who before the War had earned a total of £196 5s. 9d. in 12 weeks, had earned £460 19s. 8d. in the corresponding weeks in 1917, one man having earned £7 a week. At that time the increase on pre-war rates was 136 per cent.

It is difficult to give any account of the way in which wages have been altered in the bottle trade. In those factories which were under the control of the Association of Glass Bottle Manufacturers, a basis wage list was in existence before the War, on which an advance of 6 per cent. had been made before 4 August, 1914. The subsequent changes, which appear in the following list, show a total alteration in wages of 64 per cent. on the original basis :—

22 November, 1914	1	per cent. on	Base Wages.
18 July, 1915	10	,,	,,
3 January, 1916	5	,,	,,
12 June, 1916	6	,,	,,
9 October, 1916	7	,,	,,
14 May, 1917	6	,,	,,
3 December, 1917	6	,,	,,
18 March, 1918	8	,,	,,
30 September, 1918	8	,,	,,
16 December, 1918	7	,,	,,
	64	,,	,,

In the London flint bottle trade, chiefly manufacturing medicine bottles and similar articles, there was also a basis list previous to the War. As soon as the War began this list was upset by competition amongst manufacturers, and piece-work prices were increased during

the war from 80 per cent. to 150 per cent. In December, 1918, it appeared probable that a new basis list would be arranged between the manufacturers as a body and the workmen.

In the lampblown glass industry piece-work wages were the rule, though in the case of time workers, men's wages rose to 1s. 6d. an hour or more for highly skilled glass-workers.

In the pressed glass trade, the only trade in which the department had any serious influence, prices were advanced approximately 10 per cent. on 11 November, 1915, and subsequently the following war bonuses were added :—

March, 1915	3s.
March, 1916	3s.
May, 1916	1s.
October, 1916	1s.

A demand for a considerable war bonus was made in January, 1918, which led to a strike which was not settled until 23 September, 1918, when, at a meeting presided over by the Optical Munitions Department, a final settlement of all outstanding difficulties was made, and an increase in wages of 25 per cent. was agreed to.

VI. Trade Disputes.

Though intervention in trade disputes was the special function of a separate section of the Labour Department, the Optical Munitions Department intervened from time to time, their action being justified by the possession of special technical knowledge of the trade.

On the optical munitions side, the disputes or unrest were due largely to dissatisfaction with piece-work rates or the application of bonuses. One of the earliest of these disputes, which arose at Messrs. R. & J. Beck's in February, 1917, had as its ostensible cause the transfer of a Belgian workman from one shop to similar work in another shop, but on full investigation it was found that the real cause was a difference in methods of payment for piece-work in the different glass-working shops, some employees being guaranteed their time-rate when on piece-work and others not. It was settled by guaranteeing the time-rate equally in all shops.

On 2 April, 1917, trouble arose at Messrs. Culver's works, because a very generous piece-work price which had been in existence for prisms for tank supply was followed by an ill-conceived scheme for piece-work prices on goggles for the Army Spectacle Department. A new piece-work rate was fixed, and a bonus on output given to the foreman by arrangement between the department and the firm.

On 12 October, 1917, Messrs. Beck were again in difficulties owing to the Committee on Production giving awards which discriminated between men under and over 18 years of age, while their apprenticeship system made apprenticeship end at 21. A ruling,

however, that such awards did not affect shop practice settled the point once and for all. Another difficulty was the objection of piece workers to be put on time for such work as the making of proof-plates, which the men claimed to be worthy of a special rate like toolmaking in an engineering shop. Proof-plates, however, are of all degrees of difficulty, and a guarantee that no man would be asked at any time to give more than a fixed number of hours per week to such work eventually settled the dispute.

At the end of the same month difficulties arose at Messrs. Ottway's works regarding piece-work prices. The Wages Regulation Department had sanctioned a general addition of 5 per cent. to piece-work rates on telescopes, but this did not satisfy one group of workers. The Wages Regulation Department were unwilling to make a concession, but, on the advice of the Optical Munitions Department, the group of workers in question were given 10 per cent., while certain other rates remained unaltered. This proved acceptable to all parties.

A serious strike at Messrs. Ross' works occurred in the first week of November, 1917, where a foreman had dismissed one workman for incompetence, and the manager another for leaving a few minutes before the proper time. In twelve hours the strike had spread to 550 workpeople. There were features in both cases which appeared to put the firm in the wrong, and on the advice of the Optical Munitions Department the strike was settled by reinstating the first man, pending impartial investigation of his work and the immediate reinstatement of the second. The strike was over in 24 hours after its start, and it is interesting to note that the first man left Messrs. Ross of his own accord before the investigation of his work was made.

In the glassware trades only one serious dispute occurred, that in the pressed glass trade, which began in January, 1918. The strike lasted for nine months, during which the men found other employment equally or more remunerative. The employers in the same period made use of unskilled labour, chiefly boys, and, as most of their ware was suitable for manufacture by this diluted labour, they felt themselves in a large measure independent of the men. The strike was settled in September, 1918, when, the end of the War being in sight, the men became anxious to return to their normal work. They even agreed to the retention of boys in the industry, which at one time they would not agree to, as they regarded the boys as blacklegs. On the other hand, the men were compensated by a 25 per cent. advance in wages.

VII. Training Schools.

(*a*) The Optical Munitions Training School.

Early in the war it was recognised that the output of optical munitions was limited by a shortage of optics, due to the small number of skilled glass-workers. Isolated attempts were made by some of the manufacturers to cope with the difficulty, but with little success. Owing to the absence of a general apprenticeship system in this industry,

and the inducements offered to boys in other trades, it was impossible to draw on boy labour to any great extent. Women, however, were available, and it was considered that lens and prism work was eminently suitable for them; but the introduction of large numbers of unskilled workers into the glass shops would have resulted in disorganisation, loss of time on the part of the skilled workers while teaching, waste of valuable material, and loss of output through working machines at less than their maximum rate. Again, most of the optical manufacturers did not believe that women could be used on this type of work, and would not spontaneously co-operate in the training of women workers.

The Optical Munitions Department of the Ministry of Munitions, therefore, started a training school for the training of women in lens and prism work, a special grant of £3,500 for equipment and £2,500 per annum for instruction and wages being made by the Treasury. As the Northampton Polytechnic Institute, Clerkenwell, E.C. 1. already possessed a Technical Optics Department and the necessary teaching staff, it was decided to open the school in this Institute, the Governing Body being willing to lend for this purpose a number of rooms formerly used as engineering laboratories. These were equipped to accommodate 60 students, and the first 10 students began work on 22 May, 1916.

In order that the training school should be up to date, and the training be on the lines of modern workshop practice, the co-operation of optical munitions manufacturers was obtained, and a committee was appointed, one or two members of which visited the school weekly for a time to give advice and criticism to both instructors and students. The committee, however, ceased to fulfil its duties after a few months, and soon appeared to lose all interest in the school.

With a view to turning out highly-skilled workers, it was decided to admit to the training course only women of good education. Thus the first ten students, who were chosen to be trained as supervisors capable of training others, included four University graduates, all with a good knowledge of optics. This standard very soon had to be lowered, and the majority of students have been drawn from various occupations, such as shop assistants, domestic servants, clerks, dressmakers, etc. At first the students were obtained by the Women's Service Bureau, but later on recruiting was done by newspaper notices published by the Special Intelligence Department of the Ministry, by advertisements issued by the Polytechnic, and by employers and Labour Exchanges.

The question of the most suitable age was a difficult one, but experience showed that the younger the better, and preference was therefore given in later times to applicants between the ages of 16 and 30, although some women outside these ages were very successful.

It was anticipated that during the first year about 190 students would pass through the school, and that about 20 per cent. of these would be trained as supervisors, capable of undertaking the training

of others. Actually, during the two and a half years of the school's existence, 280 students were enrolled, making an average of 120 per year. Not all of these, however, were able to complete their training, and many had to give up the work after entering the factory owing to ill-health or for domestic reasons. The majority of trainees took posts as ordinary workers in optical munitions factories in various parts of the United Kingdom. Six at different times acted as charge-hands in the training school, and three became inspectors under the department. Very few obtained posts as supervisors or charge-hands in factories, manufacturers preferring to train their own workers for these posts.

During the last five months of the War four wounded soldiers were trained in the school at the request of the Ministry of Pensions.

The first students received from the Ministry a maintenance grant of 10s. per week, rising by degrees to 15s. as more skill was acquired. Manufacturers were not at first asked to contribute towards the cost of training. They did not approve of the scheme, but were surprised at its results. Some nine months after the school had been started, the position was different; it was clear that women could be used on this type of work, for the demand for the trainees was greater than the supply. The manufacturers were asked to contribute if they wished the scheme to go on, and they agreed to pay 10s. per week.

Later on it was felt that the low maintenance grant was deterring many would-be trainees from taking up the work, and it was decided to increase the grant to 15s. per week to workers under 18 years of age, and 25s. per week for those over 18 years of age. This brought the maintenance grant up to the same as that paid to students in the other training schools of the Ministry. This new rate came into operation about the middle of October, 1917.

It was originally intended to have two courses of instruction, Course "A," lasting twenty weeks, to be taken by selected students who showed themselves capable of benefiting by more extensive training, and who gave evidence of their capability to train others or to act later as supervisors, and Course "B," lasting ten weeks, for those wishing to become skilled in one operation. Owing to the lack of a demand for supervisors, the first course was soon suspended, and all students were trained on one operation—either roughing, smoothing and polishing, or centring, edging and balsaming.

As time went on it became evident that the period of training was too long, the average length being about sixteen weeks, and further, that the type of training given was not such as to meet the requirements of manufacturers. This was probably due to two factors: first, that it had not been sufficiently realised that the training was for the purpose of dilution to meet war-time conditions, and that for this purpose it was necessary that the students should become efficient at their particular operations in the shortest possible time; secondly, that the methods of instruction in the training school had been too academic, and not sufficiently on factory lines.

Instructional methods were then thoroughly revised, the manufacturers being asked to give exact details of the type of work which the student would be required to undertake in the factory, and in this way the training was made more practical.

Instruction was at first given on lenses of shallow curve and short diameter, involving the manipulation of small blocks, but later, in order to meet the requirements of manufacturers, lenses and prisms of all types were undertaken, and the school proved that women could successfully tackle large blocks of 2-in. diameter telescope O.G.s, working to limits of three rings on the test plate. After it had been proved that women could do first-class optical work, manufacturers began to train their own workers, and the demands for trained workers gradually decreased. In December, 1917, the number of students in the school was 43, of whom only five were unallocated, but the numbers gradually decreased until in September, 1918, the total number of women in training was only 23. It then became necessary to consider whether the school should be closed down, especially as the cost per student worked out to about £40, but as telescope optics were very urgently needed, the school was completely reorganised on factory lines in order to meet this demand. It was proposed to give the school a contract for 1,000 complete sets of X8 telescope optics to be made in four months, but the carrying out of this scheme was prevented by the signing of the Armistice, and the school was closed down on 18 January, 1919.

The training school fulfilled the objects for which it was started. It certainly proved to sceptical optical manufacturers that women could do first-class optical work, and they were genuinely surprised at the progress made by the first ten students, one of whom was able to make test-plates at the end of three months. It also provided many manufacturers with a nucleus of trained women workers. With the exception of Messrs. Ross, Hilger and Hamblin, all the other important firms in or around London employed girls from the school, and students were also sent to Messrs. Grubb, Dublin; Messrs. Barr & Stroud, Glasgow; Messrs. Armstrong, Manchester; and Messrs. Aldis, Birmingham. Some firms, such as Messrs. Dollond, Hughes, Watson, drew practically all their women workers from the school. Other firms, including Messrs. Aitchison, Ottway, Periscopic Prism Company, and Negretti & Zambra, never made the best use of those of their workers who had been trained at the school. This was almost entirely due to the antagonism of the foremen, backed up by the glass-workers, who either treated the trainees as fully skilled, and therefore requiring no help or supervision, or placed all kinds of obstacles in the way of their making progress. Great credit was due to some of the workers for the way in which they put up with almost insulting treatment from the foremen.

The Northampton Institute gave very valuable assistance to the training school. It gave the use of the workshops rent free, and also gave the services of some of the staff (outside the training

school staff) and the use of apparatus, thus contributing in a great measure to the successful development of the scheme.

(b) The Dorchester Instructional Factory.

Late in 1917, when the department became responsible for clinical thermometers, insulated chemical thermometers, and artificial eyes, the supply problem was a serious one. The artificial eyes in particular constituted a very difficult problem, because only about six really skilled workmen existed in the kingdom. The War Office was therefore asked to inquire whether amongst the German prisoners there were any men capable of undertaking the manufacture of these stores. By 28 August, 1917; they reported that about 18 men claimed to have some knowledge of the processes involved in the manufacture of one or other of these stores.

As the War Office was unwilling that the prisoners of war should be allowed out of camp except under careful supervision, and insisted that they should return to camp at night, it was rather difficult to find a place at which a factory could be set up in which the German prisoners could be used to train English workmen in the same way as has been done by the French at Vanves. After careful consideration, it was decided (October, 1917) that the prisoners should be concentrated at the Dorchester Prisoners of War Camp and a small factory established in the neighbourhood. By the end of the year Treasury sanction for a capital expenditure of £1,000, with a maintenance grant of £5,000 per annum for training purposes, was obtained.

Various initial difficulties occurred, and it was soon found that none of the prisoners had any satisfactory knowledge of the production of artificial eyes. Indeed, of the eighteen prisoners concentrated in the camp only six were really useful in the scheme.

About this time a great demand for dairy thermometers arose. These had hitherto been made by not more than three firms in the country, and the production was inadequate to meet the demands of agriculture. The prisoners were accordingly started on this kind of work, and the results of their labour were distributed to the trade through Messrs. Negretti & Zambra.

The first attempt at using the prisoners to teach British workmen was made in April and May, 1918. Four disabled men were engaged to start learning the trade by the Training Section of the Ministry, but, unfortunately, the German prisoners said that if the men came down they would immediately cease work and return to camp, and the attempt to get training done proved abortive. The products of the school, however, were of considerable value to the dairy farming industry from April, 1918, onwards.

A further attempt was made to secure the co-operation of the German prisoners in teaching in September, 1918. A little bribery in the shape of extra cigarettes and a little extra food made them agree to undertake training, and matters were further improved

by a small bonus given to those who participated in the training. Two discharged soldiers were sent down to begin with, and when it was seen that they were getting on satisfactorily the number was increased to six, who were in training when the Armistice was signed.

The attitude of manufacturers towards this scheme in its initial stages was quite sympathetic, but the workers in the thermometer trade did not believe in it as they thought that they had nothing to learn from Germans. Later, after the Armistice was signed, the manufacturers in many cases took a similar view. Some of the manufacturers, however, visited the school, and admitted that they had learnt something to their advantage. Everything about the school was done in German fashion, and even the benches were erected by a German carpenter.

The manufacturers of thermometers did not display any width of view, and, with one exception, did not expand their factories or their staffs during the war. The output required for Army purposes was produced at the expense often of civilian needs, and export business came to a standstill. If training had begun earlier, it would have greatly benefited the trade.

(c) Sheffield University School.

A School of Glass Technology was established at Sheffield University. Advanced courses and research in technical methods were carried on, and extension classes were formed in the various glass-making centres. About 50 pupils were trained in the School of Lampworking and 30 or 40 of them were absorbed by firms. A local firm took the largest number of these, and thus developed a new trade. The School of Lampworking also trained a few disabled soldiers.

A member of the department's staff was on the Committee governing the school, and though it had no financial responsibility for the school it took advantage of its programme, and advised manufacturers to take advantage of it.

APPENDICES.

APPENDIX I.

CONTROL ORDERS.

(*a*) **Control of Dealings in Optical Munitions.**

23 *November*, 1915.

In pursuance of the powers conferred on him by Regulation 30A of the Defence of the Realm (Consolidation) Regulations, 1914, the Minister of Munitions hereby orders that the War Material to which that regulation applies shall include optical munitions of the following classes and descriptions, that is to say :—

Prismatic Binoculars and Monoculars having a magnifying power of five times or more.

Galilean Binoculars having object-glasses with a full diameter of one and three-quarter inches or more, and a magnifying power of three and a half to five times.

Terrestrial Telescopes, portable, with an object-glass of one and a quarter inches full diameter or more, and a magnifying power of eleven times or more.

Telescopic or other optical sights for rifles.

Periscopes and Hyposcopes, using optical means other than, or in addition to, plane mirrors.

Compasses, Prismatic and the like, of an outer diameter of two and one-half inches or less, by means of which an azimuth angle can be read off simultaneously with the sighting of an object.

And in addition the following optical munitions of Admiralty or of War Office pattern :—

Rangefinders, Clinometers, Dial Sights, Mekometers, Angle of Sight Instruments, Directors, Telemeters, Apparatus for the Control of Fire, Field-Plotters.

(*b*) **Control of Manufacture of Chemical and Medical Glass.**

2 *January*, 1917.

The Minister of Munitions in exercise of the powers conferred upon him by the Defence of the Realm (Consolidation) Act, 1914, the Defence of the Realm (Amendment) No. 2 Act, 1915, the Defence of the Realm (Consolidation) Regulations, 1914, the Munitions of War Acts, 1915 and 1916, and all other powers thereunto enabling him HEREBY ORDERS that all persons engaged in the manufacture, purchase, sale or other dealings in Chemical and Medical glass or glass tubing and rod shall comply with the following regulations :—

Manufacture.

(1) No person shall manufacture any chemical or medical glass or glass tubing or rod unless the purpose for which the glass is required has been approved. Such approval must be evidenced by one or other of the following which must be quoted by the ordering firm together with the purpose for which the glass is required :—

(*a*) Reference to and number of an Admiralty, War Office or Ministry of Munitions contract for which the glass is necessary, or

(*b*) A certificate authorising the supply issued on behalf of the Minister of Munitions by the Director of Optical and Glassware Munitions.

(2) Manufacturers are required to render to the Director of Optical and Glassware Munitions, at regular intervals, full and accurate returns of their manufacture and output of chemical and medical glass and glass tubing and rod in accordance with the directions from time to time given by the said director.

Purchase and Sale Outside the United Kingdom.

(3) No person shall buy, sell or deal in any chemical or medical glass or glass tubing or rod situated or to be manufactured outside the United Kingdom unless a certificate authorising such purchase, sale or dealing has been issued on behalf of the Minister of Munitions by the Director of Optical and Glassware Munitions.

Definition Clause.

(4) For the purpose of this order chemical and medical glass shall include resistance, chemical and bacteriological glassware, carboys, thermometers, glass for miners' safety flame lamps, glass for X-ray apparatus, hospital glassware and glass vessels (graduated or otherwise) manufactured for the purpose of containing reagents, drugs, medicines, pharmaceutical or biological substances or preparations, and glass tubing and rod shall include all glass tubing and glass rod made by the process of drawing.

(5) All applications in reference to the above order should be made to the Director of Optical and Glassware Munitions, Ministry of Munitions of War, 117, Piccadilly, London, W.

> *Note.*—Certificates will be granted to dealers to order reasonable quantities of chemical and medical glass and glass tubing and rod for the purpose of stock and/or export, provided that such orders are not considered by the Minister of Munitions as likely to interfere with the execution of orders required for war purposes. No further authorisation to dispose of such stocks will be required, provided that in the case of articles, the export of which is prohibited, the usual permit to export be obtained.

(*c*) **Instructions to make Returns of Stocks of Photographic Lenses.**

19 *January*, 1917.

The Minister of Munitions in exercise of the powers conferred upon him by the Defence of the Realm (Consolidation) Act, 1914, the Defence of the Realm (Amendment) No. 2 Act, 1915, the Defence of the Realm (Consolidation) Regulations, 1914, the Munitions of War Acts, 1915 and 1916, and all other powers thereunto enabling him hereby orders that all persons having in their possession or under their control any photographic lens or lenses of the natures specified in the schedule hereto shall, within seven days from the date hereof, send in to the Director of Optical and Glassware Munitions, 117, Piccadilly, London, W., returns containing the following particulars with regard to such lens or lenses :—

(1) Focal length.
(2) Maximum aperture.
(3) Name of maker.
(4) Designation given by maker.
(5) Number given by maker.
(6) Type of diaphragm.

THE SCHEDULE ABOVE REFERRED TO.

(*a*) Anastigmatic lenses having focal lengths of from 8 in. to 12 in. inclusive and an aperture of not less than F/4·5.

(*b*) Anastigmatic lenses having focal lengths of from 18 in. to 24 in. inclusive and an aperture of not less than F/6.

(*c*) Anastigmatic, symmetrical, and rapid rectilinear lenses having focal lengths of from 22 in. to 26 in. inclusive and an aperture of not less than F/11.

(*d*) Anastigmatic, symmetrical, and rapid rectilinear lenses having focal lengths of from 30 in. to 72 in. inclusive and an aperture of not less than F/8.

(*d*) Control of Dealings in and Treatment of Blast-Furnace Dust.

7 *August*, 1917.

The Minister of Munitions in exercise of the powers conferred upon him by the Defence of the Realm Regulations, the Munitions of War Acts, 1915 and 1916, and all other powers thereunto enabling him hereby orders as follows :—

(1) No person shall buy, sell, deal in or dispose of any blast-furnace dust except under and in accordance with the terms of a licence issued on behalf of the Minister of Munitions by the Controller of Potash Production.

(2) No person shall treat any such dust so as to extract any component part thereof except under and in accordance with the terms of a licence issued as aforesaid.

(3) All persons producing or in possession of blast-furnace dust shall make returns in regard to rate of production, stocks, purchases, sales, dealings or other matters relating to blast-furnace dust in such form and at such times as may be required by the said Controller.

(4) Samples of any blast-furnace dust produced by or in the possession of any person shall be furnished to the said Controller by such person in such form and quantity and at such times as the said Controller may prescribe. Such samples shall be taken in such manner as the said Controller or his authorised representative may prescribe.

(5) For the purpose of this order blast-furnace dust shall mean dust deposited or otherwise derived from the gases of any furnace used for treating ores for the production of iron or any of its alloys.

(6) All applications in reference to the above order should be made to the Controller of Potash Production, Ministry of Munitions, 117, Piccadilly, W. 1.

(*e*) Control of Manufacture of and Dealings in Glass and Glassware.

GLASS CONTROL (CONSOLIDATED) ORDER, 1917.

19 *September*, 1917.

The Minister of Munitions, in exercise of the powers conferred upon him by the Defence of the Realm (Consolidation) Act, 1914, the Defence of the Realm (Amendment) No. 2 Act, 1915, the Defence of the Realm Regulations, the Munitions of War Acts, 1915 and 1916, and all other powers thereunto enabling him, hereby orders as follows :—

(1) Every person shall, as from the date hereof, in the ***manufacture of glass and glassware***, comply with all directions and regulations applicable to such manufacture, whether of general application or otherwise, which may from time to time be given or made by the Director of Glassware Supply on behalf of the Minister of Munitions.

(2) As from the date hereof no person shall manufacture and no manufacturer shall supply or deliver any chemical and medical glass (excluding bottles), or any electric lamp glass or any glass tubing and rod, except :—

(*a*) In fulfilment of an order in writing given by an ordering firm (which expression shall include every person, firm or company giving an order) who shall have furnished to the manufacturer a declaration in writing stating that they are the holders of a direct contract from the Admiralty, War Office or Minister of Munitions, and specifying the reference and number of such direct contract, and stating that the glass specified in the order is required for the purpose of fulfilling such direct contract and for no other purpose ; or

(*b*) in fulfilment of an order in writing which has been submitted to and approved by the said Director on behalf of the Minister of Munitions, and a copy of which has been received by the manufacturer duly certified by the said Director as so approved ; or

(*c*) under and in accordance with the terms of a licence issued by the said Director on behalf of the Minister of Munitions.

(3) Every declaration made by an ordering firm for the purposes of this order shall be signed by a partner, director, manager or other responsible official, and every statement contained therein shall be true and accurate.

(4) No person shall as from the date hereof buy, sell or deal in any chemical and medical glass, or any glass tubing and rod situated or to be manufactured outside the United Kingdom except under and in accordance with the terms of a licence issued by the said Director on behalf of the Minister of Munitions.

(5) No person shall as from the date hereof buy, sell or deal in any electric lamp glass, whether situated or to be manufactured in or outside the United Kingdom, except under and in accordance with the terms of a licence issued by the said Director on behalf of the Minister of Munitions ; provided that nothing contained in this clause shall be deemed to prohibit the supply or delivery of any electric lamp glass by the manufacturer thereof in accordance with the provisions of Clause 2 hereof, or any purchase or sale of or other dealing in any electric lamp glass which forms part of a manufactured article, the total value of which exceeds four times the value of the electric lamp glass forming part thereof, and which is *bona fide* sold with such glass.

(6) All persons shall furnish to the said Director as and when required by him such returns of glass and glassware at any time manufactured, purchased, sold, supplied or delivered by them at such times and in such form as the said Director shall from time to

time direct. All persons heretofore required to furnish returns relating to glass and glassware shall, until further notice, continue to furnish returns in accordance with such previous requirements.

(7) Nothing in this order shall affect any obligation to obtain from the Board of Trade (Department of Import Restrictions), 22, Carlisle Place, S.W. 1, or otherwise, import licences for the import of glass and glassware.

(8) For the purpose of this order the expression "glass and glassware" shall include all kinds of glass or glassware *made at the furnace, in the blowpipe flame, or by any other process, or any of them ;* and the expression "chemical and medical glass" shall include resistance, chemical and bacteriological glassware, carboys, thermometers, miners' safety-lamp glasses, X-ray tubes and valves, and glass for X-ray apparatus, artificial glass eyes, hospital glassware and glass vessels (graduated or otherwise) manufactured for the purpose of containing reagents, drugs, medicines, pharmaceutical or biological substances or preparations, or any of them ; and the expression "electric lamp glass" shall include all glass used or intended for use in the manufacture of electric lamps, except glass used or intended for use in lamp caps for insulating purposes, but shall not include glass shades and similar accessories ; and the expression "glass tubing and rod" shall include all glass tubing and glass rod made by the process of drawing, or either of them.

(9) The orders of the Minister of Munitions dated respectively 2 January, 1917, and 23 March, 1917, relating to certain classes of glass and glassware, are hereby cancelled, but such cancellation shall not affect the previous operation of those orders or the validity of any action taken under them or either of them, or the liability to any penalty or punishment in respect of any contravention or failure to comply with the same respectively prior to their cancellation or any proceeding or remedy in respect of such penalty or punishment.

(10) All applications in reference to the above order should be made to the Director of Glassware Supply, Ministry of Munitions of War, 117, Piccadilly, London, W. 1.

(11) This order may be cited as the Glass Control (Consolidated) Order, 1917.

Explanatory Notes.

(*a*) Subject to any directions or regulations which may be given or made by the Director of Glassware Supply applicable to the manufacture of glass and glassware and to any priority directions, a manufacturer may without licence accept any orders for glass and glassware, other than chemical and medical glass (excluding bottles) and electric lamp glass and glass tubing and rod, and manufacture the glass and glassware required to carry out such orders.

(*b*) As all chemical and medical glassware (excluding bottles) and electric lamp glass and glass tubing and rod are subject to the

provisions of Clause 2 of the above order, no materials of this kind may be manufactured or supplied or delivered by a manufacturer unless the requirements of that clause have been complied with.

(*c*) In order to obtain the approval referred to under Clause 2 (*b*) of the above order it will be necessary for ordering firms to submit their orders in duplicate to the said Director, accompanied by a covering letter setting out the purpose for which the glass and glassware is required. If approved, one copy of the order will be forwarded direct to the manufacturer duly certified and the other copy will be retained by the said Director. An advice will be sent to the ordering firm indicating the action taken in respect of such order.

(*d*) Licences may be granted to manufacturers under Clause 2 (*c*) of the above order to accept and carry out orders from dealers for reasonable quantities of the glass and glassware affected by that clause for the purpose of stock or export. Licences may also be given to manufacturers to manufacture limited quantities of such glass and glassware for their own stock or export. Licences to manufacturers to manufacture for their own stock may be given in such a form as will make it unnecessary to obtain any further licence for disposing of or dealing in the glass or glassware manufactured under such licence except in the case of electric lamp glass. A dealer who has obtained any glass or glassware in compliance with the provisions of Clause 2 of the above order will not require any further licence for disposing of or dealing in such glass or glassware, except in the case of electric lamp glass.

(*e*) In the case of electric lamp glass to be supplied by a dealer and not by a manufacturer in order to obtain the licence of the said Director for the purchase or sale of or other dealing in electric lamp glass situated in the United Kingdom, the order on the dealer for which a licence is desired must be submitted in duplicate to the said Director accompanied by a covering letter setting out the purpose for which the glass is required. If approved, one copy of the order will be forwarded direct to the dealer and the other copy will be retained by the said Director. An advice will be sent to the ordering firm indicating the action taken in respect of such orders. No licences to purchase, sell or deal in electric lamp glass situated in the United Kingdom will be granted unless these conditions have been complied with.

(*f*) No licence is required under the above order to be obtained for the purchase or sale of or other dealing in glass and glassware situated or to be manufactured outside the United Kingdom other than those types of glass and glassware affected by Clauses 4 and 5 of the above order.

(*g*) In order to obtain the licence of the said Director for the purchase or sale of or other dealing in any glass or glassware of the types affected by Clauses 4 and 5 of the above Order situated or to be manufactured outside the United Kingdom, full details must be submitted in duplicate of the glass and glassware which it is proposed

to buy, sell or deal in, accompanied by a covering letter stating the purpose for which the glass and glassware is required and to whom it is to be supplied. If approved, one copy of such details will be certified as licensed and returned to the person submitting it, who must be the actual importer of the glass and glassware in question, and such certificate will constitute his authority for the purchase, sale or other dealing. No further licence will be required to dispose of or deal in such glass and glassware except electric lamp glass, provided nothing to the contrary is specified in the licence issued as authority for purchase, sale or delivery. A licence given to an importer to buy, sell or deal in glass and glassware situated or to be manufactured outside the United Kingdom may be in such a form as will make it unnecessary for any further licence to be obtained, whether by the seller or the buyer, for disposing of or dealing in such glass and glassware except in the case of electric lamp glass.

(*h*) A licence to buy, sell or deal in glass and glassware situated or to be manufactured outside the United Kingdom will only be given on condition that the importer renders to the said Director full and accurate returns of his imports, stock and deliveries of glass and glassware in accordance with the directions from time to time given by the said Director.

(*i*) Special attention is directed to Clause 7 of the above Order relating to the necessity of obtaining import and other permits and licences which are or may be from time to time required.

(*f*) **Control of Dealings in Potassium Compounds.**

17 *October*, 1917.

The Minister of Munitions in exercise of the powers conferred upon him by the Defence of the Realm Regulations and all other powers enabling him hereby gives notice and orders as follows :—

1. No person shall as from the date hereof until further notice offer to purchase, purchase or take delivery of any potassium compounds as defined in Clause 3 hereof except under and in accordance with the terms of a licence issued on behalf of the Minister of Munitions by the Controller of Potash Production, or offer to sell, sell, supply or deliver any such potassium compounds to any person other than the holder of such a licence and in accordance with the terms thereof; provided that no such licence shall be required—

(*a*) By the Admiralty or War Office.

(*b*) By any person for the purchase and delivery of potassium compounds in quantities not exceeding in weight an aggregate of 3 lb. avoirdupois during any one calendar month.

2. All persons shall furnish returns to the Controller of Potash Production at the times and in the manner prescribed by him of all potassium compounds held in stock by them or otherwise under their control or manufactured, produced, bought, sold or otherwise dealt in by them.

3. The potassium compounds to which this order relates are caustic potash (KOH), chloride or muriate of potash (KCl), carbonate of potash (K_2CO_3) and sulphate of potash (K_2SO_4), whether in a pure or in a commercial form, and any material (other than blast-furnace dust referred to in the Order of the Minister of Munitions of 7 August, 1917), of which more than 10 per cent. consists of any one or more of the above.

4. All applications in reference to the above Order to be addressed to The Controller of Potash Production, Ministry of Munitions, 117, Piccadilly, W.1.

(*g*) **Control of Manufacture and Sale of Compound Fertilisers.**

THE COMPOUND FERTILISERS ORDER, 1918.

4 June, 1918.

The Minister of Munitions, in exercise of the powers conferred upon him by the Defence of the Realm Regulations, and of all other powers enabling him, hereby Orders as follows :—

1. This Order shall take effect as on and from 5 June, 1918.

2. For the purpose of this Order and the Schedules hereto, the following expressions shall have the following meanings :—

" Potash " shall mean compounds of Potassium calculated as Potassium Oxide soluble by the methods prescribed by the Fertiliser and Feeding Stuffs (Method of Analysis) Regulations, 1908.

" Compound Fertiliser " shall mean any fertiliser or substance intended or sold for use as a fertiliser (however described or named) which is manufactured or made by mixing or compounding together, artificially, any two or more separate substances. Provided that the product obtained by treating with sulphuric acid, or any similar reagent, a single substance containing nitrogen phosphates and potash, or any one or more of such constituents, shall not be regarded as a compound fertiliser for the purposes of this Order.

" Unit " shall mean 1 per cent. by weight in 1 ton of Fertiliser.

" Maker of Compound Fertilisers " shall mean a Mixer or Compounder of any Compound Fertiliser as above defined.

3. For the purposes of this Order the maximum prices for Compound Fertilisers shall be as follows :—

(*a*) In the case of sales for delivery free on rail, cart, barge or ship at maker's works, the basis price for Compound Fertiliser of the description sold to be arrived at as provided in Clause 7 of this Order with the addition of a charge for mixing or

compounding, bags and bagging, not exceeding 25s. per ton, and with the addition also (in the case of sales of less than two tons) of the extra distribution charges authorised under paragraph (*b*) (i) of this clause in the case of sales of similar quantities *ex* vendor's store or shop or *ex* warehouse.

(*b*) In the case of sales for delivery elsewhere than at maker's works the maximum prices authorised under paragraph (*a*) above for sales of quantities of two tons and upwards for delivery free on rail at maker's works with the following additions, namely :—

(i) In the case of sales for delivery *ex* vendor's store or shop or *ex* warehouse (other than maker's store or warehouse at point of manufacture) the following extra distribution charges according to the quantity of Compound Fertiliser included in the sale, namely :—

Quantity sold.	*Additional price authorised.*
1 ton and over	10s. per ton.
2 cwt. and over but less than 1 ton ...	1s. per cwt.
1 cwt. and over but less than 2 cwt. ...	2s. per cwt.
28 lb. and over but less than 1 cwt. ...	3s. per cwt.
Over 14 lb. but less than 28 lb.	4s. per cwt.

(ii) In the case of sales for delivery *ex* railway goods yard or public wharf, an extra distribution charge at the rate of 2s. 6d. per ton of Compound Fertiliser included in the sale. Provided that this additional charge shall not be made in the case of sales of more than 1 ton.

(iii) In the case of all sales for delivery elsewhere than at maker's works all costs of transport of the Compound Fertiliser from maker's works to place of delivery, any cartage or haulage to be charged at not exceeding local rates.

4. On sales of 2 tons and upwards by makers to Agricultural Merchants and Dealers or to Co-operative Companies and Societies incorporated or registered under the Industrial and Provident Societies Acts or any other Act the maximum prices fixed by Clause 3 of this Order shall be reduced by a discount or allowance to the purchaser, such discount to be 5s. per ton where the maximum price of the Compound Fertiliser (after deduction of such discount) is less than £6 per ton, and 7s. 6d. per ton where the maximum price (after deduction of a 5s. discount) is £6 per ton or upwards.

5. The maximum prices fixed by this Order are net cash prices for Compound Fertiliser in maker's or vendor's bags or other packages, net weight, excluding weight of bags. When credit is given to the purchaser a reasonable extra charge may be made, provided that the discount allowed for net cash is quoted on the invoice, and is such as to bring the net cash price within the maximum authorised. If

purchaser's bags or other packages are used or the purchaser takes delivery in bulk without bags a reasonable allowance shall be made to the purchaser. Where Compound Fertiliser is sold for delivery in bags (other than paper bags) containing less than 2 cwt. each, an extra charge of 4d. per bag may be made beyond the maximum price which would otherwise have been authorised.

6. The maximum prices fixed by the foregoing provisions of this Order are for sales of Compound Fertilisers for delivery during December, 1918. In the case of sales of Compound Fertilisers for delivery during other months the maximum prices are in each case to be reduced or increased 1s. 6d. per ton per month, according as the month for delivery precedes or is subsequent to December, 1918, but with a maximum decrease and increase of 7s. 6d. per ton, *e.g.*, the maximum prices for sales of Compound Fertilisers for July, 1918, delivery will be 7s. 6d. less per ton, while the maximum prices for sales for May, 1919, delivery will be 7s. 6d. more per ton than the maximum prices fixed as above for sales for December, 1918, delivery.

7. For the purpose of Clauses 3 and 9 of this Order the basis price for any Compound Fertiliser shall be the aggregate value of the Nitrogen Phosphates and Potash contained in the Compound Fertiliser when valued at the respective unit rates specified in the first schedule hereto, and distinguishing in the case of Nitrogen between the two classes of Nitrogen, and in the case of Phosphates between the three descriptions of Phosphates, also specified in the first schedule. In arriving at such basis price nothing shall be allowed or added for the value of any constituents of the Compound Fertiliser other than Nitrogen, Phosphates and Potash.

8. As on and from the date on which this Order takes effect no person shall sell or purchase or offer to sell or purchase any Compound Fertiliser at a price exceeding that prescribed by this Order as the maximum price (having regard to quantity, composition, packages, date for and terms of delivery) for such sale. Provided that—

(*a*) A Vendor of Compound Fertiliser shall not be liable to conviction for selling at a price in excess of the maximum price prescribed by this Order if the invoice given to the purchaser, as required by Clause 9 of this Order, states accurately within the limits of error allowed by that clause the percentages of the different constituents therein referred to contained in the Compound Fertiliser sold and the price charged and stated on such invoice does not exceed the correct maximum price on the basis that the percentages stated in such invoice are correct; and

(*b*) A Purchaser of Compound Fertiliser shall not be liable to conviction for purchasing at a price exceeding the maximum price unless the price agreed to be paid by him is to his knowledge in excess of the maximum price authorised for such purchase.

9. As on and from the date on which this Order takes effect, no person shall sell any Compound Fertiliser without giving to the purchaser on or before or as soon as possible after delivery an invoice stating :—

(*a*) The percentage contained in such Compound Fertiliser of each of the following constituents contained therein, namely :—(i) Class I. Nitrogen ; (ii) Class II. Nitrogen ; (iii) Water Soluble Phosphate ; (iv) Citric Soluble Phosphate ; (v) Insoluble Phosphate ; and (vi) Soluble Potash, all as more particularly defined in the First Schedule hereto (such percentages to be stated accurately in the case of each constituent within the limits of error specified in the second schedule hereto) ;

(*b*) The maximum unit rates authorised to be charged for each of such constituents as specified in the first schedule hereto ;

(*c*) The basis price for such Fertiliser in which may, however, be included any charge made for credit ;

(*d*) All addition made to such basis price in arriving at the actual price charged for such Fertiliser (including the maker's charge, not exceeding 25s. per ton, for mixing or compounding, bags and bagging) ; and

(*e*) The price charged for the Compound Fertiliser, and where such price includes an extra charge for credit, the discount allowed for net cash.

10. None of the foregoing provisions or restrictions of this Order as regards maximum price or otherwise shall apply to :—

(*a*) Any sale of any Compound Fertiliser for export from the United Kingdom to any country other than the Channel Islands or the Isle of Man.

(*b*) Any sale of any Compound Fertiliser in quantities not exceeding 14 lb.

(*c*) Any sale of Compound Fertiliser in quantities exceeding 14 lb., where the Compound Fertiliser is sold for horticultural purposes, packed in special bags, tins, boxes or cartons, each branded or marked with the maker's or vendor's name and address, and the words "horticultural fertiliser," and containing not more than 14 lb.

(*d*) Any sale of any Compound Fertiliser for delivery prior to 1 July, 1918.

11. As on and from 1 July, 1918, no person shall manufacture or produce any Compound Fertiliser, nor shall any maker of Compound Fertiliser sell any such Fertiliser, except under a licence issued by or under the authority of the Minister of Munitions, and in accordance with any terms and conditions of such licence.

12. All persons engaged in producing, making, selling, distributing or storing any Compound Fertiliser shall make such returns with regard to their businesses, and shall verify the same in such

manner (including production of their books to any accredited representatives of the Minister of Munitions) as shall from time to time be required by or under the authority of the Minister of Munitions.

13. None of the foregoing provisions or restrictions of this Order shall apply to a sale, by a maker to a consumer, of two or more Fertilisers or substances, neither of which is by itself a Compound Fertiliser as defined by this Order, notwithstanding that it is one of the terms of the purchase that the Fertilisers or substances purchased are to be artificially mixed or compounded together by the maker before delivery, provided that such Fertilisers or substances are sold separately by description as such, and that an invoice is given to the consumer on or before or as soon as possible after delivery which states the quantity and price of each of the Fertilisers or substances included in the mixture or compound as delivered, and the charge made for mixing or compounding, bags and bagging.

14. This Order and the Fertilisers and Feeding Stuffs Act, 1906, shall operate and have effect independently of one another, and nothing contained in this Order shall be held to exempt any person from compliance with any of the provisions or requirements of such Act, or any Regulations made thereunder, applicable to sales or purchases of Compound Fertilisers; nor shall any of the provisions of the said Act or Regulations be held to govern or affect any of the requirements or provisions of this Order, or any proceedings instituted in respect of any breach thereof.

15. This Order supersedes the Orders relating to Compound Fertilisers made by the Minister of Munitions on 13 October, 1917, and 14 November, 1917, excepting only as regards sales or purchases of Compound Fertilisers made before or after the date of this Order for delivery before 1 June, 1918.

16. This Order may be cited as "The Compound Fertilisers Order, 1918."

Note.—All applications in reference to this Order should be addressed to the Director of Acid Supplies, Ministry of Munitions, Department of Explosives Supply, Storey's Gate, Westminster, S.W. 1.

THE FIRST SCHEDULE.

Unit rates of Nitrogen, Phosphates and Potash for the purpose of the above Order.

Class 1. Part 1—Nitrogen.	Unit rate.
Derived from sulphate of ammonia, salts of ammonia, nitrate of soda, or other salts of nitric acid, cyanamide, meat, blood, bone, slaughter house refuse, ground horn, ground hoof, guano, fish offal, fish meal, fish guano, oil seed cakes or meals, or dissolved shoddy, dissolved wool waste or dissolved silk waste as below defined	18s. 6d.

Note.—The expression "dissolved shoddy," "dissolved wool waste," and "dissolved silk waste" shall mean shoddy wool waste and silk waste treated with sulphuric acid or any similar reagent in such a way that at least 80 per cent. of the fibre is destroyed.

Class 2.	Unit rate.
Derived from other sources	7s. 6d.

Description. Part 2—Phosphates.

" Water Soluble," *i.e.*, rendered soluble in water	4s. 3d.
" Citric Soluble," *i.e.*, insoluble in water, but soluble in a 2 per cent. solution of Citric Acid in the manner prescribed by the Fertilisers and Feeding Stuffs (methods of analysis) Regulations, 1908	2s. 6d.
" Insoluble," *i.e.*, insoluble either in water or in a 2 per cent. solution of Citric Acid in the manner prescribed by the said Regulations	1s. 6d.

Description. Part 3—Potash.

" Soluble," *i.e.*, soluble by the methods prescribed by the said Regulations	25s. 0d.

THE SECOND SCHEDULE.

Limits of error referred to in Clauses 8 and 9 of the above Order.

Nitrogen Class 1.	*Nitrogen Class 2.*	*Phosphate water soluble.*	*Phosphate citric soluble.*	*Phosphate insoluble.*	*Potash soluble.*
·3	·3	1	1	1	·3. If the percentage of potash stated in the invoice does not exceed 4.
—	—	—	—	—	·5. If such percentage exceeds 4.

Note.—The above figures for limits of error represent percentages of the whole bulk of the Compound Fertiliser.

(*h*) Control of Dealings in Radio-Active Substances, Luminous Bodies and Ores.

RADIO-ACTIVE SUBSTANCES CONTROL ORDER, 1918.

13 *August*, 1918.

The Minister of Munitions, in exercise of the powers conferred upon him by the Defence of the Realm Regulations and all other powers enabling him, hereby orders and gives notice as follows :—

(1) The substances, bodies and ores to which this order applies are all radio-active substances (including actinium, radium, uranium, thorium and their disintegration products and compounds), luminous bodies in the preparation of which any radio-active substance is used and ores from which any radio-active substance is obtainable except uranium nitrate, and except radio-active substances at the date of this order forming an integral part of any instrument, including instruments of precision or for timekeeping.

(2) As from the date hereof until further notice no person shall offer to purchase, purchase or take delivery of any substance, body or ore to which this order applies except under and in accordance with the terms of a licence issued on behalf of the Minister of Munitions by the Controller of Optical Munitions, or offer to sell, sell, supply or deliver any such substance, body or ore to any person other than the holder of such licence and in accordance with the terms thereof.

(3) All persons shall furnish returns to the Controller of Optical Munitions at the times and in the manner from time to time prescribed by him of all such substances, bodies and ores to which this order applies as may for the time being be held in stock or dealt with in any manner by them.

(4) This order may be cited as the Radio-active Substances Control Order, 1918.

(5) All applications in reference to this order are to be addressed to The Controller of Optical Munitions, Ministry of Munitions, 117, Piccadilly, London, W. 1.

APPENDIX II.

(CHAPTER I., p. 5.)

Organisation of the Optical Munitions and Glassware Department in November, 1918.

MR. A. COLEFAX, K.C.,
Controller.

MR. E. BATTY,
Assistant Controller.

Optical Adviser—Prof. F. J. CHESHIRE, C.B.E.
Chemical Adviser—Sir HERBERT JACKSON, K.B.E., F.R.S.
Adviser on British Potash—MR. K. CHANCE.

Geological Adviser—Prof. P. G. H. BOSWELL, D.Sc., F.G.S.
Adviser on Furnaces and Refractories—Prof. J. W. COBB, B.Sc., F.I.C.
Adviser on Wireless Valves—Prof. E. WILSON.

TECHNICAL AND LABOUR QUESTIONS.	CONTINENTAL SUPPLY.	GLASSWARE.	OPTICAL MUNITIONS.	GENERAL SERVICES AND STATISTICS.	POTASH PRODUCTION.
Mr. S. W. MORRISON, O.B.E., Section Director.	Mr. S. C. DANNATT, Section Director.	Mr. R. S. BIRAM, Section Director.	Mr. T. KNOWLES, Section Director.	Mr. J. D. MILLS, Section Director.	Mr. R. B. RANSFORD, Section Director.
Technical questions relating to optics, glassware, pots, clay and furnaces—chemical questions—radium control—dilution.	Administration of Paris Office.	Supply of scientific and other glassware and vacuum glass apparatus—glassware inspection—administration of glassware control.	Supply of optical and scientific instruments and navigational instruments, mathematical and survey instruments—administration of progress inspection.	Accountancy costs—statistics — drawing office.	Gas-cleaning plant—special services connected with British Potash Co. and Oldbury Factory—investigation of new sources of supply, control and distribution of potash compounds.

APPENDIX III.

Tables showing the Principal Demands for Optical Munitions and Glassware to 2 November, 1918.

(*a*) Optical Munitions.

Instruments.	*Total No. Demanded.*
Alidades	219
Binoculars, Various Types	202,354
Clinometers, Various Types	74,772
Compasses, Various Types	292,603
Directors, Various Types	9,856
Directors, Gun, Wilson Dalby	130
Stands, Director, Various	8,435
Instruments, Angle of Sight	1,564
Mekometers, Right and Left	706
Mekometer Reels	12,873
Periscopes, Various and French	51,241
Periscopes, Mortar, Trench, and 17-in.	6,785
Periscopes, Giant	76
Plotters, Field	3,455
Plotters, Aircraft Observation	2,800
Rangefinders, Artillery	3,146
Stands, Rangefinders, Artillery	2,548
Bubbles, S.G., Various	80,694
Rangefinders, Infantry	10,724
Stands, Rangefinders, Infantry	10,527
Sights, Dial, Various	11,609
Sights, Dial, Ill. App.	15,700
Sights, Telescopic, for Rifles	13,464
Sights, Optical, for Rifles	75,900
Sights, Luminous Machine Gun	228,050
Telemeters, Artillery	1,755
Stands, Tripod Telemeter	2,780

Instruments.	*Total No. Demanded.*
Telescopes, Field Artillery	2,098
Telescopes, Sighting	31,919
Telescopes, Sighting, No. 9	1,956
Telescopes, Observation, Special	406
Stands, Telescope, Field Art.	1,230
Telescope, Signalling	24,002
Telescope, Stereoscopic	901
Telescope, Variable Power	1,889
Stands, Teles., Variable Power	2,389
Stands, Teles., Signalling	23,814
Stands, Teles., Stereoscopic	877
Stands, Teles., Observation	476
Stands, Teles., Garrison	146
Periscopic Bomb Sights	301
Collimators, Double	50
Collimators, Teles. Sighting	2
Telescopic Gun Sights	500
Camera Precision for aerial gunnery and Hythe	651
Camera Precision	1
Sights, Unit Telescopic	11,815
Binoculars, Graticuled	29,200
Microscopes, Miscellaneous	620
Plotters, Obs. of Fire	1,000
Pyrometer Apparatus	36
Pyrometer Outfits	220
Oscillograph Outfits	22

(*b*) Glassware.

Articles.	*Total No. Demanded.*
Acetone, Rectified	21 lb.
Alcohol, Absolute	60 lb.
Acid, Various	241 lb. 2 oz.
Ampoules	130,000
Ammonium, Various	23 lb. 12 oz.
Apparatus, Various	122
Apparatus, Accessories	54
Atomisers, Scent Sprays	6
Balance Parts	9
Basins	727
Beakers	20,477
Benzole	12 lb.
Blowers	4
Boats, Porcelain	12

Articles.	*Total No. Demanded.*
Boards	61
Books	88
Borers	3 sets
Bromine	1 lb.
Bottles, Various	18,477,728 and 1,510,025 per week
Bottles, Accessories	128,228
Baths, Various	158
Baths, Accessories	20
Bulbs	3,820
Bushings, Quartz	4,000
Butyrometers	70
Burettes	2,340
Burettes, Accessories	34

(*b*) Glassware—*continued.*

Articles.	*Total No. Demanded.*
Caustic Soda (Sticks)	7 lb.
Calorimeter	1
Candles, Filter	67
Charcoal, Blood	4 oz.
Clips	54
Carboys	850
Chloride	66½ lb.
Chloroform, Various	40 lb.
Cones, Various	272
Condensers	259
Crushmeters	300
Containers, Various	1,213,720
Extractor, Lemon Juice	1,000
Corks	1,260
Crucibles	900
Deck Lights	1,296
Desiccators	65
Dishes, Various	49,902
Diamonds for Writing on Glass	2
Ether, Various	70½ lb.
Eyes, Glass	50,000
Filters	100
Flasks	52,040
Flasks, Accessories	4,500
Glasses, Test, Conical	5,000
Glasses, Accessories	2,000
Funnels	34,532
Gaines, Porcelain	50
Gauzes, Wire	12 and 12 pieces
Gauge U., Inclined	1
Glasses for Covering Instruments	7,632
Glasses, Clock	114
Glasses, Signalling	52,000
Glasses, Observation	200
Glass, Various	300 lb., 20 ft. 7,089 pcs., 10,835 sq. m.
Glasses, Various Beverage	1,346,025
Glasses, Gauge	11,168, 1,500 ft.
Glasses, Medicine	64,860
Glasses, Micro. Cover	19,200, 9 lb. 5 oz.
Glasses, Ruby and Green	11,000 prs.
Glasses, Sediment	6,000
Glasses, Time	18
Glasses, Triplex	1,000 pcs.
Glasses, Watch	6,938, 50 prs.
Glasses, Well, E.L. Fittings	14,288
Glasses, Medicament, Daffens	900
Goggles	77,128
Goggles, Parts for	307,002
Hæmacytometers	1
Hydrometers	844
Hydrometers, Accessories	600
Jars, Medical, Various	12,770
Iron Sulphide Sticks	14 lb.
Jars, Various	4,615,138
Jugs, Glass Tank	6,000
Lamps	1,154

Articles.	*Total No. Demanded.*
Iodine	½ lb.
Globes	501,966
Lamp Glasses	7,214
Lamp Chimneys	99,746
Labels	2,000
Lamp Accessories	6,300
Indigo	1 oz.
Lenses	3,057
Manometers	100
Measures, Various	133,270
Lactometers	2
Millboard	6
Mirrors	395
Mortars and Pestles	386
Needles, Various	138,993
Oil, Various	3 lb., and 6 pts.
Nitrometers	19
Nozzles, Medical	160,455
Papers, Various	7,137
Panes, Various	5,400
Pencils, Triplex Glass	1,000
Pencils, Accessories	1,000, 500 ft.
Pipettes	18,730
Pipettes, Accessories	16
Pencils	[illegible]
Plasticine	14 lb.
Perhydrol	300 grms.
Potassium	16 lb.
Plates, Various	6,058
Pumps, Various	89
Pycnometers	6
Pitchers, Syrup, Glass	250
Rings	12
Rods, Glass	132, 48½ lb.
Shades, Various, and Stands	19,330
Scales	24
Slabs	300
Shells, Porcelain	50
Pots, Brass	10
Pumice Stone	2 lb.
Saccharometers	100
Salt, Rochelle	2 lb.
Slides for Microscopes	143,148
Sodium	96 lb. 4 oz.
Soxhlets	8
Samplers	10
Saucers, Porous	36
Stillheads, Various	34
Stirrers	24
Stands	215
Sugar, Cane, Pure	8 oz.
Stopcocks	378
Swabs	1,000
Sulphate, Various	13 lb.
Syringes	63,177
Syringes, Repairs	1,181
Syringes, Accessories	870
Tableware, Various	5,739,076
Taps	27

(*b*) GLASSWARE—*continued.*

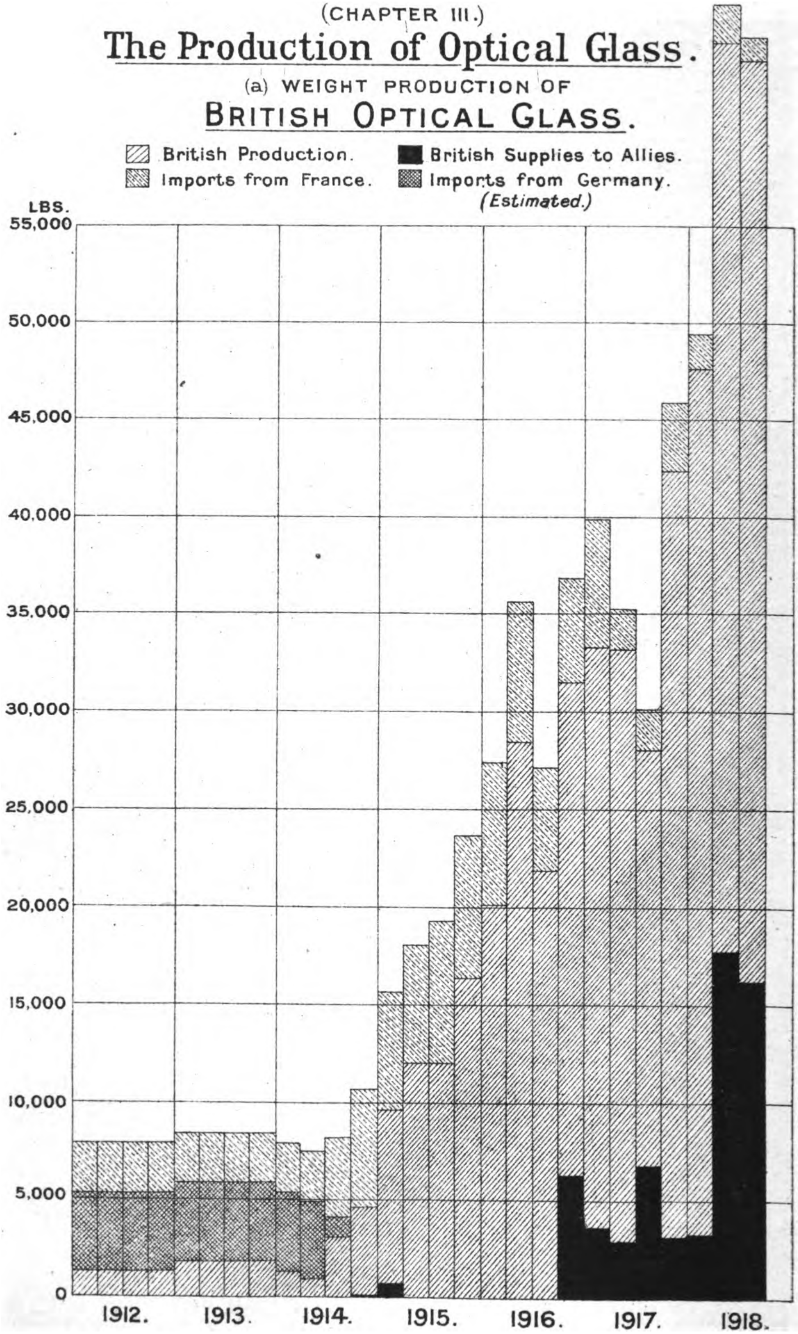
Articles.	*Total No. Demanded.*	*Articles.*	*Total No. Denmanded.*
Thermometers, Clin., Various	1,002,727	Ureometers	2,000
Thermometers, Various	21,138	Urinals	46,089
Thermometers, Repairs	16	Urinometers	2,300
Tanks	10	Vessels	124
Triangles, Pipe Clay	108	Valve Tubes	2,020
Tools, Various	6,024	X-Ray Tubes	7,627
Towers	6	X-Ray Accessories	315
Tubes, Various	443,911	X-Ray Tubes, Repairs	313
Tubing, Various	375 lb., 557 ft.	Slides, Moist Chambers	144
Tubing, Accessories	42	Sulphur, Various	4 lb.
Wire, Copper	3 lb.	Zinc	2 lb.

APPENDIX IV.

(CHAPTER III.)

The Production of Optical Glass.

(a) WEIGHT PRODUCTION OF BRITISH OPTICAL GLASS.



9375. 3843. A.P. 5036. 250.10.20.

Malby & Sons, Lith.

(*b*) VARIETY PRODUCTION OF BRITISH OPTICAL GLASS.

Type of Glass.	No. of Varieties Marketable by Messrs. Chance Bros. in 1912.	No. of Varieties Marketable by Messrs. Chance Bros. and Messrs. Wood Bros. in 1918
Fluor Crown	0	1
Boro-silicate Crown	1	8
Dense Barium Crown	1	11
Hard Crown	0	7
Light Barium Crown	0	3
Zinc Crown	0	1
Medium Barium Crown	0	3
Soft Crown	1	1
Light Barium Flint	0	6
Barium Flint	0	1
Extra Light Flint	1	4
Light Flint	3	9
Boro-silicate Flint	0	1
Dense Flint	3	10
Extra Dense Flint	1	2
Double Extra Dense Flint	0	4
Triple Extra Dense Flint	0	1
Total	11	73

APPENDIX V.

(CHAPTER III., p. 58.)

Experiments in Tempering Pot Clays.

If raw pot clay be ground up and mixed with a large bulk of water, the mixtures will clear by subsidence far more completely and rapidly than a similar mixture of the same clay which has been tempered. Also if a moistened mass of the raw clay be divided into two parts, one of which is left above in a covered vessel and the other is heated in its moist state to about 60 deg. C. during the day and cooled during the night, or any other sequence of alternate heating and cooling for periods varying from a day to a week, the latter half is found to be the more tempered, as shown by its plasticity of masses and rate of subsidence of aqueous suspensions of clays so treated. (A reservation on the possible useful action of acids will be referred to later.)

Careful comparison of the appearance under the microscope of a large number of pot clays in the raw and tempered states revealed certain facts about them which appeared to have a direct bearing on the mechanism of tempering. In all the pot clays examined there appeared, in addition to the coarser masses of aluminium silicate, quartzite, etc., numbers of minute particles varying in sizes and shapes within fairly narrow limits. Most of these particles were round or oval, some spherical, some flattened spheres and some minute thin oval and circular plates, while some again were minute definite crystals. So far as it was possible to examine them under polarised light, the relatively larger spheres and ovals were bi-refringent, the minute crystals were definitely so. So far also as it was possible to separate them out for the purpose, chemical analysis pointed to the greater part of them being of the nature of kaolinite with aluminia and silica in the proportions shown by the formula $Al_2O_3.2Si\ O_2$; the minute definite crystals appeared to be quartzite. In raw pot clays relatively few of these particles are free and independent, the bulk of them being either clumped together or adherent to masses of aluminium silicate or of quartzite. In fully tempered clays the reverse was seen to be the case, the greater part of the fine particles having left the larger masses and the clumps being disintegrated. If powdered raw pot clay be examined in water under the microscope the relatively few free minute particles are seen to exhibit Brownian movements. A similar preparation of the same clay fully tempered is crowded with free particles all showing the same kind of movements. By selecting under the microscope small portions of clay covered with adherent fine particles and small portions consisting of clumps of fine particles, it was found possible, by placing these portions in a small cell and feeding in water, to watch the process of resolution

and disintegration. With distilled water it was very slow, but with dilute ammonium oleate the separation of the fine particles and breaking up of the clumps could be followed from hour to hour quite distinctly.

Two permanent sealed up cells were made, one (*a*) containing raw clay in water and the other (*b*) the same clay in a very dilute solution of ammonium oleate with a slight excess of ammonia. In about three hours practically all Brownian movement in (*a*) ceased, and after a week none was observable, the fine particles which were at first free having adhered to the glass of the cell or to one another or to bigger portions of clay and quartzite. In cell (*b*) the movement continued to persist to some extent, but several of the numerous fine particles adhered to the glass of the cell and to larger masses. However, while tapping cell (*a*) released no particles, tapping cell (*b*) readily released almost all the fine particles, and Brownian movement became again as lively as at the first. Now it is important to note that in the case of cell (*a*) the amount of water relatively to the clay would represent a very thin aqueous suspension as it would in cell (*b*), but in this case there was also present a chemical agent, viz., ammonium oleate, and it is clear that in cell (*b*) the tenacity with which the fine particles adhered to the glass or larger bits of clay was far less then in the case (*a*).

If it were admitted that one part of the mechanism of tempering of clay was revealed by the preceding brief survey of experiments on rates of subsidence of aqueous suspension of pot clays and of the experimental observations by the microscope, and that non-adherence to one another and the rest of the clay and freedom for independent movement of the smaller constituents of the clay is a condition associated with the state called tempered, there remained the question, what is the nature of the changes occurring during tempering which bring about, foster, and maintain that condition? Were these changes to be ascribed to agents in the clay existing as such and brought into play by the mere solvent action of water, or did they result from chemical action during the long period of tempering? For example, clay treated with much water and alternately heated and cooled did not show anything like the same advance in tempering as results from only moistening the same clay and heating and cooling the prepared lumps. Moreover, when clay was mixed with a large volume of water and one-half of the mixture was gently evaporated to the consistency usual for tempering, while the water after warming was removed from the other half by filtration, the plasticity of the former half was markedly the greater. Both these observations pointed to the effect of chemical agents, since the purely physical effect of changes of temperature were considered to be similar in each case; but the concentration of any possible agents was far less where much water was used. Hence heating and cooling an aqueous suspension or heating and cooling the same amount of clay moistened with a very little water were two very different things, since in the latter case any chemical agents were at their fullest possible concentration and were only in extremely dilute solution in the former case.

The effect of evaporating gently the whole of the water mentioned just above pointed in the same direction, since the possible agents were fully preserved and were progressively in greater concentration of the effect of alkalis, sodium silicate, ammonium oleate, some gums, albumen, etc., and a whole series of experiments, based on a long investigation carried out on the behaviour of detergent agents, generally led up to the view of tempering which may be shortly expressed as follows :—

In weathered pot clays there are all sizes of particles, some homogeneous, like quartzite and portions of the true kaolinite, and of relatively large size. Some, on the other hand, are composed of smaller particles temporarily stuck together, and in all pot clays described as good there is a good proportion of very minute particles adherent for the most part to one another or to the larger constituents of the clay. During tempering the various composite masses of particles become unstuck and are then free to move with their appropriate velocity, *i.e.*, according to their size and density. The balance of evidence was in favour of the unsticking being brought about, in some cases, by the solvent action of water on the traces of cementing material, in some cases by the more marked action of agents produced by chemical action during the exposure of the clay while it is tempering, *e.g.*, the action of small quantities of sulphuric acids produced by the slow oxidation of such a body as iron pyrites present in the clay, or it may be that solvents and disintegrating agents are formed by changes connected with the growth of bacteria. (The fact that tempering of sterilised clay is possible does not necessarily exclude the agency of bacteria in some cases). Whatever the process of unsticking was, good plasticity appeared to be associated with the maintenance of the free and unstuck condition of the smaller constituents of the clay, and this condition was undoubtedly fostered by the absence of such substances as mineral acids of metallic salts, the solution of which are known to be good electrolytes by the presence of small amounts of alkalis or bodies like sodium silicate, ammonium oleate, etc., or by the presence of small amounts of collodial substances such as may be considered to arise from slow changes of the organic matter present in many clays, changes which in some cases may be ascribed possibly to oxidation or in other cases to the influence of bacteria. Direct introduction of various colloids into slightly acid clays showed that the influence of electrolytes to bring about the adherence to one another of the particles was held in check by the presence of certain colloids. Some of these deductions are summarised and extended in the text on page 58.

APPENDIX VI.

(Chapter IV., p. 73.)

Outline of the Process of Recovery of Potash from Blast-Furnace Dust.

The dust derived from the gases of furnaces in which the salt process is used are different from those produced in normal blast-furnace working. In normal working, the hot gases from the furnace after passing through a " dust catcher " are burnt under boilers and in " stoves," in which the air forming the hot blast for the furnaces is heated. The dust catcher collects a relatively heavy dust, poor in potash, but in the stoves and boiler flues a finer dust collects as the gases burn, and these dusts are moderately rich in potash—so rich as to form a very useful potash fertiliser. Large quantities of stove and boiler flue dust were collected and distributed under control during the war for fertiliser use.

When salt is added to the blast-furnace charge, however, the nature of the dust changes profoundly. It comes off as a fine impalpable powder, the potash content of which may be as high as 50 per cent. of muriate (or chloride) of potash. These dusts can only be removed by specially designed gas-cleaning plants. The Halberg-Beth type contains fabric bags through which the dirty gas is forced while on its way to gas-engines or other plants, where it undergoes combustion. The dust retained in the bags may contain cyanides and other ingredients harmful to plant life, and for this reason they are not suitable for direct application to the ground. Their potash content is extracted, under suitable chemical control, and becomes available as muriate of potash, the standard potash fertiliser.

Blast-furnace dust as received is lixiviated in vats, from which it passes to filter presses. The pressed mud is removed and the liquor is carried to a main storage tank, whence it passes to a concentration plant, feeding a Kestner evaporator plant. The crystals of muriate are separated by centrifugal spinners and are delivered in dry condition on the bagging floor. The Kestner plant is fed by exhaust steam from the power-house, and the whole power for the factory is generated from Babcock and Wilcox boilers working at 160 lb. pressure and 200 deg. superheat, with an exhaust from the engines (for compressing air and generating electricity) at from 10 lbs. to 15 lbs.

APPENDIX VII.

(CHAPTER V., pp. 100, 101.)

List of Processes upon which Women are successfully Employed in Connection with Instrument Making and Glassware Manufacture.

Note.—Where not otherwise stated, women work under skilled male supervision, and do not set up or grind their tools. The list of operations given below is chosen as typical, and many other examples could be given of similar operations on other instruments.

(*a*) OPTICAL GLASS WORK.

Lens Work.—Slitting glass on slitting machine. Shanking glass roughly to size. Roughing with coarse emery to limit plus or minus ·01 in. on vertical or horizontal power-driven spindle. Malletting or "pitching on." Truing with fine emery. Blocking up on "runner." Smoothing with finer grades of emery by hand or machine. Making pitch or wax polishers. Polishing with rouge or putty powder to two rings on test plate. Centring and edging on lathe to gauge. Chamfering edges of lenses. Cementing lenses with Canada balsam. All cleaning and testing operations.

Prism Work.—Roughing and truing to angle. Blocking up in plaster of Paris. Smoothing and polishing flat surfaces to uniform colour on test plate. Cementing parts of complicated prisms for rangefinders.

Graticule Work.—Cutting and edging discs for graticules. Blocking, smoothing and polishing graticule blanks. Ruling and etching graticules.

Miscellaneous.—Silvering mirrors. Washing and grading emeries. Preparing pitch. Acting as charge hands capable of training on all operations.

Types of Optics.—Complete lens systems for such instruments as prism binoculars (including 10 lenses and 4 prisms); telescopes (including O.G., object lens, amplifying triplet, field lens, eye-piece, and condensing lens); periscopes; sextant telescopes; dial sights (the accurate prisms for these are worked up to the finishing stage, which is completed by skilled men). The highest class of optical work yet done by women is the polishing of 4 in. diameter photographic lenses for aircraft photographing apparatus.

All types of prisms for optical instruments and magnifying prisms for all types of compasses.

(*b*) INSTRUMENT WORKING.

(The instruments given below are typical of work done in instrument making; many other examples can be given of similar operations.)

Prism Binoculars. All operations.

(i) *Machine Operations,* including the following which are chosen as typical :—Milling prism seatings in bodies on vertical milling machine. Milling hinge faces. Boring and screwing bodies on chasing arm lathe. Filling and finishing bodies and joint lugs at vice. Drilling and tapping bodies for plate screws and prism springs. Drilling and tapping prisms, clips, knurled rings, grub screw holes for eye-pieces, etc. Stamping out cover plates on power press. Drilling, countersinking, and surfacing cover plates. Cutting threads and finishing O.G. cells on lathe. Cutting, screwing, turning and finishing eye-piece tube. Turning " V " groove in eye-piece lining. Grinding in eye-piece lining to jacket. Turning, boring and cutting off pillar covers. Burnishing O.G. in cells. Turning ebonite eye-cups by hand or machine. Covering bodies with rubber prior to the vulcanising process.

(ii) *Fitting and Assembling.*—Fitting collets to bodies, and securing with grub screw. Fitting prisms to shoes, shoes to bodies, covers and clips to prisms. Cutting collet to free motion of adjusting clip. Squaring prisms in bodies. Screwing on plates. Mounting of O.G.s and eye-pieces. Fitting graticule and adjusting. Fitting index washers, bushes and lanyards.

(iii) *Engraving.*—Name plates, diopter rings, etc., on Taylor, Taylor and Hobson Engraving Machine.

(iv) *Final checking on collimator for adjustment.*

(v) *Finishing processes.*—Bronzing and enamelling (spraying) of all parts. Filling in with waterproof wax, etc.

Telescopes (such as Sighting Telescopes No. 9, Variable Power Telescope No. 1, Admiralty Gun-sighting Telescope).

Machine Operations, such as :—Cutting to lengths of such parts as body tubes, object lens tube and cell ; amplifying lens tube ; field lens cell, on Holbrook lathe. Threadmilling of such parts as body tubes, focussing eye-piece tubes and rings, bezelling rings, lens cells, eye-piece caps, focussing eye-piece screws on thread milling machine (24, 32 or 40 threads to the inch). Thread milling part of focussing tube arrangement on Herbert lathe, working to micrometer head. Turning operations on Herbert capstan lathe to limits of plus or minus ·0035 in. Internal threading of such pieces as eye-piece adapter on Holbrook lathe. Slotting of amplifying lens tube on Pratt and Whitney hand miller. Boring operations on Ward lathe, to limits of plus or

The effect of evaporating gently the whole of the water mentioned just above pointed in the same direction, since the possible agents were fully preserved and were progressively in greater concentration of the effect of alkalis, sodium silicate, ammonium oleate, some gums, albumen, etc., and a whole series of experiments, based on a long investigation carried out on the behaviour of detergent agents, generally led up to the view of tempering which may be shortly expressed as follows :—

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Prism Work.—Roughing and truing to angle. Blocking up in plaster of Paris. Smoothing and polishing flat surfaces to uniform colour on test plate. Cementing parts of complicated prisms for rangefinders.

Graticule Work.—Cutting and edging discs for graticules. Blocking, smoothing and polishing graticule blanks. Ruling and etching graticules.

Miscellaneous.—Silvering mirrors. Washing and grading emeries. Preparing pitch. Acting as charge hands capable of training on all operations.

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All types of prisms for optical instruments and magnifying prisms for all types of compasses.

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(ii) *Fitting and Assembling.*—Fitting collets to bodies, and securing with grub screw. Fitting prisms to shoes, shoes to bodies, covers and clips to prisms. Cutting collet to free motion of adjusting clip. Squaring prisms in bodies. Screwing on plates. Mounting of O.G.s and eye-pieces. Fitting graticule and adjusting. Fitting index washers, bushes and lanyards.

(iii) *Engraving.*—Name plates, diopter rings, etc., on Taylor, Taylor and Hobson Engraving Machine.

(iv) *Final checking on collimator for adjustment.*

(v) *Finishing processes.*—Bronzing and enamelling (spraying) of all parts. Filling in with waterproof wax, etc.

Telescopes (such as Sighting Telescopes No. 9, Variable Power Telescope No. 1, Admiralty Gun-sighting Telescope).

Machine Operations, such as:—Cutting to lengths of such parts as body tubes, object lens tube and cell; amplifying lens tube; field lens cell, on Holbrook lathe. Threadmilling of such parts as body tubes, focussing eye-piece tubes and rings, bezelling rings, lens cells, eye-piece caps, focussing eye-piece screws on thread milling machine (24, 32 or 40 threads to the inch). Thread milling part of focussing tube arrangement on Herbert lathe, working to micrometer head. Turning operations on Herbert capstan lathe to limits of plus or minus ·0035 in. Internal threading of such pieces as eye-piece adapter on Holbrook lathe. Slotting of amplifying lens tube on Pratt and Whitney hand miller. Boring operations on Ward lathe, to limits of plus or

minus ·002 in. Burnishing lenses in cells. All bronzing and enamelling processes. Final cleaning and assembling of various parts. Testing collimation on collimator.

Compass Work.

(i) *Aero Compass,* made throughout, operations including:—Burnishing compass bowls. Soldering centres into base, lugs to sides, and rings to face of bowl. Facing and shaping rings on capstan lathe. Dividing rings. All drilling and filing operations. Making wire "floats" by shaping round a frame and then soldering into position. Pointing, cleaning and fixing needles to base of wire "float." Fixing, waxing and balancing card. Radium painting card, lubber lines and centres. Sandblasting. Testing for watertightness on air pump. Final assembling and filling with alcohol. All testing operations.

(ii) *Compass,* such as magnetic mirror compass:—Turning inside of boxes by hand. Drilling and tapping centre hole for screwing in pivot, holes in lid for screwing in mirror, all holes in side of box, half-hole in side of box, and half-hole in outside plate for fixing lever. Shaping wire for compass bows in power press. Shaping ends in power press. Drilling and tapping ends. Cutting groove for milled ring with hand tool to gauge. Bezelling glass in rim. Stamping out slot for lever with press. Screwing mirrors into lid, lubber marks into box. Setting aluminium and celluloid dials accurately to each other, and fixing to needle and jewel socket. Balancing card on needle. Turning and opening out jewel socket to obtain correct balance and pointing of pivot. Testing oscillation of dial (six movements of card for a deflection of 10 deg.). Nickel-plating boxes. Magnetising needles in induction coil. Fixing lever which fixes card; and index clamp for clamping movable glass in position for taking readings. Final testing.

Mathematical Instruments.

(i) *Spring Bows, Pencils, Pens and Dividers.* All operations, including the following:—Shaping the rough metal to form bows, forming needle-holders with power press and shaping machine. All drilling and tapping operations on sensitive drilling and tapping machines. Grinding surfaces on Universal grinder. Milling recess for needle point. Polishing surfaces on polishing head. Brazing sockets for pencil holder. Hardening in blow-pipe, tempering in lead bath. Assembling (at the rate of 100 per day).

(ii) *Beam Compasses,* 26 *in.*—Turning of brass shank on capstan lathe to limit of ·005 in. Milling of brass stamping on Denbigh milling machine to limit of ·005 in. Tapping box heads to take points. Filing and finishing small brass cylindrical parts ready for bronzing. All bronzing and engraving. Assembling and testing taper fittings for interchangeability.

Miscellaneous Operations (not included in above).

(i) Calibrating and dividing drum of large clinometer. Operation takes about five to ten hours, according to skill of worker. Limit of error allowed is 1 ft.

(ii) Operating automatic machine for cutting teeth on base plate of directors.

(iii) *Bubbles (levels) for various instruments.*—Shaping glass in blow-pipe flame. Grinding inside surfaces with emery. Marking off prior to engraving. Engraving divisions by hand engraving machine. Pointing off in blow-pipe. Filling and final cleaning. Fitting bubbles in cases and adjusting on instrument.

(iv) Cutting internal teeth on plunger of Field Clinometer, Mark "V," with Brown and Sharp slotting attachment to within 1 ft. of arc on radius of 5 in.

(*c*) Glassware Manufacture.

Glass Bottles.—Wetting off; taking in (in glasshouses where bottles are made by hand). Pressing; blowing (on press and blow machines). Blowing; paddling or taking off (on semi-automatic machines and hand machines). Taking off from lehr; sorting; packing; batch mixing (in glasshouses generally). Stoppering of finished bottles.

Pressed Glass.—Pressing; taking in (in glasshouses). Grinding and cutting. Cracking off and glazing. Blown ware.

Flint Glass, including table glass, miners' lamp glasses and furnace-made scientific glass.—Mould-making; taking in (in the glasshouses). Cracking off. Puntying, grinding. Cutting. Taking off from lehr. Sorting. Packing.

Electric Lamp Bulbs and Tubing.—Bulb blowing. Post holding for tube drawer. Cutting up tube when drawn. Sorting and gauging tube.

Plate and Sheet.—Packing and examining glass. Cleaning and polishing glass. Silvering glass. Glass drawing. Glass laying. Washing and grading emery. Cutting and packing rolled plate and sheet. Assisting and splitting. Crane driving. Pot making and clay mixing. Labouring in yard and sandfields. Cullet picking.

Safety Glass (Triplex and Duplex).—Cleaning. Coating. Cutting up. Pressing. Sealing duplex and triplex glass.

Thermometers and Hydrometers.—Clinical thermometers; hydrometers (all processes).

Medical Glassware.—Following made throughout:—Medical nozzles (Y-shaped, 2, 3, and 4-way). Syringes of all types. Serum and vaccine ampoules. Tubes for minehorns. Ligature reels and winders. Drainage tubes. Serum flasks. Blood extractors. Catgut tubes.

Chemical Glassware.—Test tubes. Thistle funnels. Hooks and guides for Courtauld's apparatus. Graduating burettes, cylinders and flasks, pipettes.

Chemical Porcelain Ware.—All processes in the manufacture of such articles as:—Evaporating dishes. Crucibles. Ignition tubes.

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VOLUME XI

THE SUPPLY OF MUNITIONS

PART IV

RIFLES

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CHAPTER I.

THE SUPPLY OF RIFLES UNDER THE WAR OFFICE.

(August, 1914–June, 1915).

I.—Position at the Outbreak of War.

(a) Administrative Organisation.

At the outbreak of war, the direction of rifle production was the duty of A3, a section of the Directorate of Artillery, which was also responsible for small arms ammunition, machine guns and certain other stores. In November, 1914, the duties of this section in regard to trench mortars and kindred stores became particularly heavy, and the responsibility for rifles and small arms ammunition was transferred to a new branch of the directorate, known as A5.[1] The manufactured weapons were tested by the staff of the Chief Inspector of Small Arms at Enfield Lock, and were stored at Weedon in charge of the Chief Ordnance Officer. Questions relating to design were referred to the Small Arms Committee for technical advice.

(b) Sources of Supply.

Rifles were manufactured for the Government both at the Royal Small Arms Factory and by the trade. The former, which has its workshops at Enfield, was administered by Section A4 of the Directorate of Artillery and orders were given by means of extracts.

For purposes of administration the factory, together with the Royal Gunpowder Factory at Waltham, was in charge of a Superintendent (Superintendent of Waltham and Enfield) who at the outbreak of war and until 1917 was Colonel F. T. Fisher. At Enfield he was assisted by Major S. C. Halse, whose official title was Assistant Superintendent of Enfield (A.S.E.). Prior to the war the factory had been reorganised, and was thus in a position more readily to expand with success.

Under a policy adopted in 1912 the Royal Small Arms Factory supplied the bulk of rifles needed for home service and the capacity on a theoretical two-shift basis was 4,200 per week.[2] The actual output, however, immediately prior to the war was about 1,000 new and 1,000 repaired rifles a week and, in addition, bayonets at 600 a week, scabbards at 700, and cavalry swords at 50 per week were turned out.[3] Spares for the Chief Ordnance Officer had also to be supplied, and all rifles to be resighted for Mark VII ammunition were dealt with at Enfield.

In addition to the Royal Small Arms Factory, two firms were employed in making service rifles, the Birmingham Small Arms Company and the London Small Arms Company. Both companies had for many

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[1] War Office Memorandum, No. 790. [2] Sec./R.S./135.B/1.
[3] O.F./Gen./039. Hist. Rec./H/1122.1/3.

years produced rifles for home service, but, consequent on the change of policy in 1912, they had during 1913 and 1914 supplied weapons chiefly for use in India and the Colonies. The Birmingham Small Arms Company had made rifles for the Government since the formation of the company soon after the outbreak of the Crimean War, and while their average output of new rifles immediately prior to the war was about 700 a week,[1] they had, in 1913, informed the Chief Inspector of Small Arms that they could turn out 1,800 a week on day shift alone.

The London Small Arms Company, whose works were at Victoria Park, E., had a pre-war capacity of 500/600 rifles a week without night shift, and just prior to the war were turning out 250 a week.

(c) TYPES OF RIFLE.[2]

The standard rifle was the " Rifle, Short, Magazine, Lee-Enfield, Mark III sighted for use with Mark VII ammunition " and known as the R.S.M.L.E. Mark III. The Mark III pattern had been introduced in 1907, but the high velocity ammunition (Mark VII) did not appear until 1911, with the result that, although the work of resighting rifles originally manufactured to take Mark VI ammunition was being done gradually, there were still in the hands of other than regular infantry divisions and of some overseas troops a number of rifles not so treated. Other patterns in use were the original short rifle first issued in 1904 and known as Mark I, of which most but not all had been brought to an ultimate pattern called Mark I***, and conversions from " long " non-charger loading rifles, which had been the standard weapon at the time of the South African War, known after conversion to short rifles as Mark II or IV according to whether the conversion had been made to approximate to the Mark I or to Mark III type. The latter (Mark III) had an improved back-sight design and a charger guide fixed to the body in lieu of to the bolt. In addition there were old long rifles, known as C.L.L.E. rifles Mark I or Mark I*, which had been modified to permit charger loading of magazines, and there were in the hands of special troops and in store some old unmodified long rifles. Some of these older patterns were sighted for Mark VI and some had been resighted to take Mark VII ammunition.

Prior to the war, experiments had been in progress with a view to producing a rifle with a lower trajectory, and 1,000 of a pattern known as the ·276 in. rifle had been issued to the troops. Completely satisfactory ammunition had not however been produced and, in consequence of this, in spite of the greater simplicity of design, it was not practicable to re-arm troops with a smaller bore rifle than that in use for service ammunition, and eventually, when rifles were ordered from the United States of America, the ·276 in. pattern was passed over in favour of a modified weapon upon much the same lines, but capable of taking the ·303 in. cartridge. The War Office were most interested in getting this pattern introduced in view of experience gained during the South African War, and though it was felt to be undesirable to interfere in any way with existing output it was thought that factory

[1] Sec./RS/135 B/1. [2] HIST. REC./H/170/5 ; HIST. REC./R/1420/10.

extensions might be turned to its manufacture; but, in spite of the preparation of comparative estimates at Enfield and attempts to persuade the Birmingham Small Arms Company, this modified rifle was never made by the rifle factories in England, although Messrs. Vickers produced a model and were given an order.[1] The American contracts[2] were all placed for this type as being simpler to manufacture and because it was considered that it would be a more satisfactory weapon. Also, as it was impossible to supply sufficient gauges to send to America, it was thought to be impracticable to manufacture R.S.M.L.E. rifles there which would be interchangeable with the home production. The original Vickers model was found to be not wholly satisfactory and certain adjustments were made in the United States by the Inspection Staff and by Mr. Reavill of the Royal Small Arms Factory who was sent out for that purpose. Eventually three modifications were produced of one pattern of the ·276 in. ·303 in. rifle, which was then called the pattern 1914 rifle. As a result, they were not fully interchangeable although in many respects they were so. The specification was approved on 22 October 1914, but the model rifles were not accepted until the end of March 1915, and even thereafter a number of changes became necessary.[3]

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The aggregate output of rifles for the period 1901 to the outbreak of war was 1,306,566 rifles, of which 410,488 were long and 896,078 short. Of these 200,242 were made for India and the Colonies.

The average pre-war rate of output of rifles sighted for Mark VII ammunition was 47,280 per annum, of which the Royal Small Arms Factory produced 25,279 for current equipment and the trade 10,400, while 11,601 were made for the replacement of stock. Up to July, 1914 an aggregate of 166,847 of these rifles had been produced, and in addition some 332,413 made to take Mark VI had been resighted for use with Mark VII ammunition, so that at the outbreak of war there were available over 475,000 rifles of the newest pattern, of which 335,000 were in the hands of troops, etc., and 140,000 were in store.

The stock of long rifles, which were used by Territorials, numbered 320,000, of which 220,000 were in the hands of the forces, and 100,000 in store. There was therefore a total stock of 795,000 serviceable rifles for the arming of the Forces at the outbreak of war, viz., 160,000 Regulars, 210,000 Reservists, and 250,000 Territorials.

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[1] See below, p. 4.
[2] See below, p. 10.
[3] See below, Chap. IV.
[4] HIST. REC./H/170/5.

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CHAPTER IV.

Supplies from Abroad.

CHAPTER V.

Review.

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[1] See below, p. 4.
[2] See below, p. 10.
[3] See below, Chap. IV.
[4] HIST. REC./H/170/5.

Mark VI and to proceed with the manufacture of the standard rifle at the greatest possible speed in anticipation of a formal order. On 9 August both companies were formally invited to tender for rifles, and in addition one of the armament firms, Messrs. Vickers (Crayford) was approached. The total number of rifles required was given as 150,000[1] of which 40,000 were allocated to the Royal Small Arms Factory and from the trade the output was to be 2,700 per week, if possible, for the first six months, with delivery of 35,000 within three months.

At the end of the year, owing to shortage of labour, lack of machinery and to the increase of troops and wastage of rifles in the field, the position was exceedingly serious, so that new units could not be trained nor drafts put in the field for want of rifles.

In January, 1915, a circular letter[2] was sent to all contractors asking whether it was within their power still further to increase output. " The Secretary of State understands," it continued, " that it is rather the shortage of skilled labour and men qualified to undertake duties of superintendence and management than any lack of materials which is likely to limit the ability of contractors to undertake further extensions." The replies from the rifle-making factories confirmed this view.

In March, 1915, Lord Kitchener tried to secure double the output, but, while arrangements for the future were promising, the immediate output, though improving, was inadequate, and in April the Lowland Division had to be sent to the Dardanelles armed with long charger-loading rifles sighted for Mark VI ammunition.

Progress at the Royal Small Arms Factory was steady but beset with difficulties.[3] Within three weeks of the declaration of war the output of new rifles was more than doubled, and by 14 November 3,000 per week were being delivered,[4] but as this result was almost entirely due to the extension of working hours and the reduction of working stock to a minimum, extra capacity became essential.

Accordingly, on 21 October, 1914, approval was given for extensions to bring the output up to 5,750 rifles a week. The extension of the bayonet plant to bring the output up to 6,000 per week was also approved and begun in November, 1914.[5]

After November, the Factory's rate of production increased more slowly, but in spite of the fact that the machinery on order was very much delayed, rifles were being turned out at the rate of about 5,000 a week by June, 1915. Repairs and conversions, estimated in September, 1914, as likely to amount to 68,000 by the end of the year actually reached nearly double that number, and the output of bayonets and of cavalry swords for which there was a large demand early in the war increased to over 2,000 and 200 per week respectively by December, 1914, and early in 1915 additional premises for repair work were erected.

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[1] Contracts/R/2085 ; Contracts/A/2623.

[2] Contracts/R/2524.

[3] For an account of the development and work of the Factory during the war, see Vol. VIII, Part II, Chap. I.

[4] Sec./R.S./135B/1. [5] O.F./Gen./039.

In March, 1915, the Superintendent was asked to submit a scheme for doubling the output of rifles, bayonets and scabbards,[1] viz., to 12,000 of each per week, but in view of the fact that the extra capacity would involve extensions which would not be productive under 21 months and of the difficulties in obtaining machinery, labour and housing accommodation, the proposal was dropped for the time. It was, however, recognised that extension of the Royal Small Arms Factory would probably lead to the surest result. In the meantime the two established contractors had increased their output.

From the Birmingham Small Arms Company[2] a tender had been received on 12 August, 1914, and although owing to their Lewis gun work they expressed their inability to reach the day rate estimated in 1913,[3] they undertook to deliver 35,000 rifles within three months and the balance up to a total of 72,800 within six months at the rate of 2,700 a week. The price was to be 75/- per rifle complete with oil bottles and pull throughs and an extra 10/6 per rifle was allowed on those produced on night shift. The delivery promised was attained, and by 30 November, 1914, the company had produced 40,627 rifles. The work which still remained to be done on a 1913 contract for Mark VI rifles had been transferred to the London Small Arms Company.

As early as 10 September, 1914, there was talk of doubling the firm's output, and on 26 September a further contract was placed for 150,000 rifles to be delivered at 3,750 per week, increasing to 6,000 a week by 30 April, 1915. To help meet the cost of the extra plant needed to reach this output the War Office promised a grant of £35,000, payable by means of an extra charge of 12/5 per rifle up to a total of 56,250 delivered in excess of 3,750 per week. No provision was made for the repayment of this grant.

Proposals followed one another in quick succession. The object of the War Office was always to procure more rifles ; the object of the company was to recoup themselves for expenditure on plant by securing orders as far ahead as possible ; but, though ready to make substantial grants in cash, the War Office strove not to commit themselves to too far reaching orders.

With a view to securing an output of 8,000 rifles a week, the contract of 26 September was, after much discussion, amended, so as to increase the order to 300,000 rifles. The company had pressed for an order for 350,000 rifles for delivery by 12 February, 1916, but although the War Office declined to cover more than the year 1915, they agreed to take the company's actual output until 31 December, 1915, stipulating that 8,000 a week should be delivered by 10 July. No other order for a fixed quantity was to be given during the war, but the company might be called upon to supply rifles at 8,000 a week until notice.[4] The price remained at 75/- for the first 200,000 and 76/6 thereafter, and a grant of £150,000 was made, and if the expected

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[1] 94/R/14.

[2] HIST. REC./H/1420/2 passim.

[3] See above, p. 2.

[4] The proportion of day to night work was to be 2,000 : 1,750 when the total was 3,750 per week, 3,250 : 2,750 when the total was 6,000, and 4,270 : 3,730 when the output was 8,000.

output was not attained a proportionate reduction was to be made on £37,500. Arrangements were also made for the repayment of part of the grant.[1]

In March, 1915, the company were pressed to double their output, but they anticipated considerable difficulty in view of housing and labour problems, doubting also the utility of so large a factory after the war, and submitted concurrently a proposal for 12,000 rifles a week as being less expensive[2] and more likely to be realised.

About this time plans for increasing the supply from America[3] were under consideration and in view of the fact that the machinery for extensions at Birmingham would have to be purchased in America, it was decided not to take up the offer of the Birmingham Small Arms Company. Lord Kitchener, however, seems to have always considered that both programmes could be embarked upon and on 19 April the company was authorised to make preparations to carry out extensions for an additional 4,000 rifles a week. The Government agreed to pay £460,000 and the firm undertook to maintain the factory as extended in good order until a reasonable proportion of the grant was repaid.

Somewhat similar arrangements had been made with the London Small Arms Company. In response to the request for tender the company had on 12 August, 1914, offered to supply rifles sighted for Mark VII ammunition at 75/- each[4] with delivery beginning at 700 a week in November increasing to 1,000 a week early in 1915. Preparations for this output had been begun when the War Office on 12 August changed their policy. "It is necessary to reconsider the decision regarding the output from trade rifle factories so as still to continue to supply as many rifles as possible towards Indian and Colonial orders. We shall probably re-arm the Colonials with our own rifles when they arrive."[5] The London Small Arms Company were accordingly instructed to revert to the manufacture of rifles sighted for Mark VI and in addition, the whole or part of the outstanding orders at the Birmingham Small Arms Company's works and at the Royal Small Arms Factory was to be transferred to them.[6] Full overtime was to be worked but no night shift and it was estimated that six months' work was in hand.

However, by the end of August, 1914, the requirements had so largely increased that the Indian orders were cancelled and the company were instructed to produce rifles for home service and also to work full

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[1] If less than 350,000 rifles were ordered, the War Office were to pay a premium of 6/- per rifle in respect of the deficiency, and if the rifles delivered should exceed 350,000 the contractor was to allow a rebate of 6/- a rifle in excess of 350,000 until £75,000 should be reached.

[2] £460,000 to be paid by the War Office as compared with £950,000 if the output was to be doubled.

[3] See below, p. 11.

[4] An increase of 3/9 per rifle due to increased cost of material, addition of oil bottles and pull throughs and necessity for overtime payment. Contracts/A/2623.

[5] *Ibid.*

[6] 6,000 remained undelivered on their own contract, 14,000 on the Birmingham Small Arms Company's contract and 16,000 on the Royal Small Arms Factory's extracts.

night shifts. A new contract for 24,000 rifles was then placed. Delivery was to be complete in six months and the eventual rate of output was to be 1,200 a week of which 700 were to be day work. For rifles produced on night shifts an additional 10/6 per rifle was to be paid.

On 22 September, 1914, the company enquired as to the probability of obtaining a further order and offered to go into the question of further increasing output, and on 4 November a further order for 20,000 rifles was given, delivery to increase to 1,500 a week by 8 March, 1915, and to be complete by 3 June, 1915.[1] The company had intimated that with an extension of plant, they could further increase their output to 2,000 rifles a week, but that financial assistance was necessary. On 15 December, 1914, therefore, a continuation order was given whereby the company agreed to raise the output to 2,000 rifles a week[2] by 10 June, 1915, and the War Office promised a grant up to £27,000. In the event of failure to attain the rate of output a refund of a proportionate part of the grant was to be made. No further definite order was to be given but the company were to proceed at their maximum output, subject to three months' notice. Further extensions were out of the question as the available land was all in process of being covered. Owing to difficulties in obtaining suitable steel, troubles with workmen, sickness and lack of good supervisors, the contracts were not fulfilled to date[3] and extensions were granted; for the month of May, 1915, the firm's total output was 5,452 rifles.[4]

Rifle manufacture was also attempted by one of the armament firms, viz., Messrs. Vickers (Crayford). The tender submitted by the company soon after the outbreak of hostilities for the supply of R.S.M.L.E. rifles at 90/- each, delivery to begin in nine months at 200 per day, or of the ·276 in. model to take ·303 in. ammunition at 86/- each was declined, but later the model of the ·276–·303 in. rifle produced by the firm was accepted and an order for 100,000 was given. The price was to be 104/- per rifle, which included overtime, night work and plant to the value of £100,000. Deliveries at the rate of 2,000 per week were to begin on 31 July, 1915, and to be increased to 3,000 a week by 27 November, 1915. The War Office authorised the company to begin operations; but the contract was not finally confirmed until 3 June, 1915.[5]

Towards the end of 1914 a project was set on foot for making use of the capacity outside the existing rifle contractors and led to the establishment of the Standard Small Arms Company.[6] Owing chiefly to the special difficulties in the manufacture of rifles,[7] orders for the production of this arm had been confined to existing rifle factories, but there was a strong feeling among the gun makers of Birmingham that although they had technical knowledge and were willing to make rifles,

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[1] The price was raised to 80/- per rifle to include night work and the cost of additional plant. For rifles undelivered at the expiration of contract the price was to be 75/-.

[2] Not less than 1,100 were to be day work. The price was to be 75/- per rifle plus 10/6 for each one made on night shift.

[3] Contracts/R/2524; 94/R/74; 94/R/149; 94/R/212; Contracts/R/2525.

[4] HIST. REC./R/1000/10.

[5] *Order and Supply Lists* E. No. 6.

[6] Contracts/R/2311.

[7] See below, Chap. V.

and were well aware of the pressing need for these weapons, their skill was being wasted. Towards the end of 1914 the War Office had declined an offer made by Mr. S. J. (later Sir Samuel) Waring to manufacture R.S.M.L.E. rifles on the ground that it would be too long before any appreciable quantity would be delivered, but a few days later, in order that the possibility of utilising the gunmakers' experience might be considered, the question was re-opened. The outcome of these negotiations was the formation of a company known as the Standard Small Arms Company, of which "the main idea was to utilise existing small makers of the country as far as possible so as to get output earlier than we should by starting from scratch." Mr. Waring was associated with Mr. Peterson, a man of standing in the Birmingham gun trade, and they proposed to build and equip a factory for the manufacture of the whole of the action parts of the rifle and nosecap, but less magazines, screws and pins, and to organise in all eight small firms and a number of individual gunmakers for the production of the remaining components. It was hoped that this organisation would ultimately be in a position to compete with the Birmingham Small Arms Company.

A contract was arranged in November, 1914. The company were to supply a minimum of 57,000 rifles at 75/- each, complete with oil bottles and pull throughs[1] at the rate of 1,250 per week from 1 June, 1915, increasing to 1,500 a week from 1 December, 1915, to 31 March, 1916. The whole of the output was to be at the disposal of the Secretary of State, and a running contract for the maximum output was to be given later. A grant of £60,000 was made for plant, and in the case of rifles supplied beyond 57,000, the price was to be governed by the conditions ruling and the prices current in the trade for the time being, and in the event of a dispute the prices were to be the same as those paid to the Birmingham Small Arms Company for similar rifles. Every assistance and encouragement were given to the new company. Men were trained at Enfield, but progress was not at all encouraging.[2]

Other attempts were also made with a view to using the engineering resources of the country. Towards the end of November, 1914, Sir Ralph Ashton, with the concurrence of the War Office, made private enquiries among certain leading Lancashire machinists, with a view to enlisting their co-operation in a scheme for increasing the output of rifles. This was done in the belief that rifle-making employed the same class of labour and machinery as the production of textile machinery, and that with government assistance, in the way of advice and access to government plant, it would be possible to extend the source of supply. The War Office stated that they would be unable to spare advisory or superintending staff owing to pressure in all factories, and were not optimistic as to the possibility of obtaining supplies within a reasonable time. Only one firm was ready to make the attempt, and the scheme was abandoned.[3]

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[1] Barrels were to be sub-let to Messrs. Westley, Richards & Co., and the machining of stocks was to be done by Messrs. Waring & Gillow and Messrs. Rudders & Payne, but both the latter firms dropped out.

[2] See below, Chap. II, III.

[3] HIST. REC./R/1420/14.

The formation of the Standard Small Arms Company was, however, a step in a somewhat similar direction, and the component pool[1] which was developed later under the Ministry of Munitions was really an elaboration of the methods which this company proposed to adopt.

In the first quarter of 1915 the possibility of augmenting the output by distributing work among firms not engaged in rifle-making was again discussed, and was the subject of an investigation by a Committee of Engineering Employers, none of whom was a rifle-maker. The unanimous conclusion was that owing to the number of small parts, the necessity for extreme accuracy and the special difficulty in the manufacture of breech mechanism and other small parts, and the difficulty of obtaining machinery, the only way to increase output was to extend the productivity of rifle shops.[2]

Even so, the idea was not lost sight of, and was brought to a practical issue as the result of a conference called at the War Office on 9 June, 1915, at which the question of acceleration as distinct from increase of output was discussed. Four proposals were considered, viz., (1) the extension of existing rifle factories, (2) the pooling of their surplus capacity for the assembly of additional rifles, (3) the production of complete rifles by farming out parts, and (4) the building up of stores of particular components so as to release part of the capacity of rifle factories for the manufacture of more difficult components. The conference agreed that the first proposal would give surer results than would an attempt to co-operate uneducated and small units over the country. The difficulties, however, in the way of collecting the necessary machinery were so great that the results for a long while to come were likely to be negligible, and it was, therefore, considered worth while to try to secure an early increase by the adoption of the third and fourth proposals. A suggestion that the pattern 1914 rifle should be made was rejected, and a sub-committee was formed to discuss the second proposal.[3] It was thought that if a workable plan could be formulated by the two trade factories, the pooling system, worked through a central information bureau, could be extended to include the smaller firms.[4]

Apart from repaired rifles which formed a considerable, though uncertain, source of supply, the work of resighting was continued as rapidly as possible. Most of this work was done at Enfield, but some was undertaken by the Birmingham Small Arms Company, who completed 155,826 by April, 1915. The decision to send the Lowland Division abroad with rifles sighted for Mark VI ammunition so reduced the number left for conversion, that the remainder were finished at Enfield, or by Messrs. Westley Richards, and by June this source of supply had come to an end.

During the first year of the war, the War Office made several small purchases; no possibility of supply, however small, was overlooked. The Birmingham Small Arms Company were instructed not to sell

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[1] See Chap. II.

[2] Minutes of the Committee on Munitions of War 20 March, 1915. Copy filed in HIST. REC./R/1420/4.

[3] See below, p. 18. See also Chap. V. [4] HIST. REC./R/1420/21.

any arms without giving the Government an opportunity to purchase, and at different times 1,120 rifles of varying types, were bought.[1] Similar purchases were made from the London Small Arms Company up to a total of 17 rifles.[2] Not a few reports of generous quantities of "spot lots" were received. At one time an offer of 150,000 Springfield rifles was made, at another 200,000 Mauser rifles were said to be lying unpacked off Vera Cruz, and a certain José Maria Braceras claimed to have the right to sell 35,000 new Mauser rifles lying off Monte Video, and 25,000 Argentine rifles,[3] but not one of these materialised. The Indian Government was able to supply 50,000 rifles,[4] and a consignment of 130,000 Japanese rifles was acquired.

The resourcefulness of the Admiralty, guided by the First Lord, supplemented the endeavours of the War Office. Much time, energy, and ingenuity were expended in April and May, 1915, upon an attempt to secure for the British forces 400,000 rifles with 900,000,000 rounds of ammunition, which were said to be lying in Rio de Janeiro, and to be controlled by a German syndicate in New York. The purchase of such consignments in neutral states by the British Government was, however, set about with considerable political difficulties, while the employment of one or more agents led to uncertainty, and tended to inflate prices. Small success, therefore, followed upon such efforts.

(*b*) SUPPLY FROM ABROAD.

The United States of America offered a most important source of supply, and for the first five months of war the War Office negotiated with the manufacturers direct or with their representatives, and the first two contracts[5] were signed by "Sir Courtenay W. Bennett, His Majesty's Consul-General at New York, acting herein for the Army Council of the War Department."

The difficulties of discriminating between reliable and unreliable brokers and other troubles consequent on the distance of the market from headquarters led to the appointment on 15 January, 1915, of Messrs. J. P. Morgan & Company as commercial agents with power to place orders, conduct negotiations and make payments. Communication with the British Government was made through Messrs. Morgan, Grenfell & Company. To some extent the War Office continued to deal through brokers, but the results were not very successful and the value of the arrangement with Messrs. Morgan was indisputable.[6]

The first rifle contracts were placed on 24 November, 1914, the one with "Marcellus Hartley Dodge, doing business under the trade name of Remington Arms-Union Metallic Cartridge Co. of New York," and the other with "The Winchester Repeating Arms Company . . . located in the Town of New Haven." In the former case the manufacturer agreed to deliver 200,000 rifles, magazine Enfield ·303 in.

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[1] 94/R/268 ; 77/15/5137 ; 94/R/107 ; 94/R/65.

[2] 94/R/154 ; *Order and Supply Lists* E. No. 6.

[3] 94/R/134 ; 94/R/44.

[4] See Vol. II, Part V.

[5] Contracts/B/7231, 7235

[6] See Vol II, Part III.

pattern 1914 with sword bayonets and scabbard complete to the approved samples, subject to alterations to be agreed between the War Department and the manufacturer. The price was fixed at \$30·00 each, and delivery was to begin from nine to twelve months from the date of acceptance of the modified rifle at 1,000 a day. For all rifles ready for shipment before 31 July, 1915, a premium of \$1·00 per rifle was offered. The contract was to close on 31 May, 1916, and such portion as covered rifles undelivered on that date could be cancelled by giving three months' notice.[1]

The contract with the Winchester Company was on similar terms except that the price was to be \$32·50 per rifle,[2] and an advance payment of 25 per cent. was allowed.

A further offer in January, 1915, from the Remington Company of Ilion was declined; but the chances of an early increase in home supply seemed so remote that the War Office re-opened the question, and, though unwilling to contract for deliveries so late as June, 1916, agreed to take a further 200,000 rifles, with delivery at 500 a week, in November, 1915, and increasing to 1,000 a week, with completion by 31 July, 1916.[3]

In March, 1915, Lord Kitchener pressed for a duplication of the Winchester Company's plant, but the firm absolutely refused to do this, offering instead to supply a further 200,000 rifles, with delivery between 1 March, 1916, and 1 November, 1916, at 300 rifles increasing to 1,300 per day. The War Office were particularly anxious not to make a further advance payment of 25 per cent. for shop expansion, but the company insisted, "pressing enquiries for their goods rendering them extremely independent." The advance was, therefore, allowed subject to a proportionate refund in respect of rifles undelivered by 1 November, 1916, and the contract was closed on 16 March, 1915.[4]

About this time Messrs. Morgan heard confidentially of a proposed new organisation for the manufacture of rifles on a large scale. In the belief that sufficient orders had been placed to cover requirements, the War Office suggested the new venture as a source for Russian supplies; but, on receipt of particulars, it appeared that the Remington Company proposed, with the co-operation of powerful interests, to develop the company with the assistance of the technical staff at the Ilion works. Accordingly, the War Department reconsidered their decision, and in spite of the heavy commitment a contract was placed on 30 April, 1915, for 1,500,000 rifles to be delivered between February, 1916, and 12 April, 1917, at 1,000 per day increasing to a maximum of 4,000 a day. In order to meet the initial expenses an advance

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[1] Contracts/B/7235.

[2] *Order and Supply Lists* No. E6. In all future contracts rifles were to be made according to the modified specification as agreed in these contracts and were to be complete with bayonets and scabbards. The price includes these accessories and delivery f.o.b. New York unless otherwise stated. No premium was allowed in any subsequent contract, and the price of future rifles was \$30.00 each.

[3] Cables: N.Y. 1026; L.1079, 2103, 2121. (A complete set of these cables is filed in the Archives Registry. "N.Y." denotes from Messrs. J. P. Morgan to Messrs. Morgan Grenfell. "L" indicates the reverse.)

[4] L.2418, 2431; N.Y. 1453, 1487, 1476; 94/R/6.

payment of 25 per cent. was made on the understanding that rifle manufacturing machinery of a normal capacity of 4,000 rifles per working day of 20 hours should become the absolute property of the buyers upon the termination of the agreement, "provided that at the date of such termination the sellers shall have delivered not less than 1,000,000 rifles."[1] The factory was to be erected near Eddystone, Pennsylvania.

Early in April the War Office placed a contract with a firm of brokers called the Imperial Contracting Company, in which they agreed to accept all rifles delivered up to 31 December, 1915, provided that the number did not exceed 400,000. This negotiation involved endless troubles, and no rifles were ever delivered.[2]

Excluding, therefore, this contract, orders had been placed in the United States for 2,300,000 rifles, of which over a million were due for delivery by the middle and nearly 2,000,000 by the end of 1916—a prospect making for considerable optimism.

In addition to the orders placed in the States, an attempt was made to obtain rifles from Canada.[3] The only source of rifle supply in the Dominion was the Ross Rifle Factory, the management of which had the exclusive right to supply the Canadian Government, from whom, after the outbreak of war, orders had been received about ten times in excess of normal capacity.

The War Office, however, in their anxiety for supplies had placed an order for 10,000 rifles with the Canadian Government, and began negotiations with the Ross Rifle Company in August, 1914. No formal contract was made, but the company, in a letter of 12 November, undertook to supply 100,000 rifles between 7 March, 1915, and 8 April, 1916, an arrangement subsequently confirmed with certain modifications on 3 June, 1915.[4]

Difficulties arose in December, 1914, when the Inspection Department insisted on the British standard of technical accuracy, while Sir Charles Ross contended that he was under contract to produce a rifle which would pass the tests imposed by the Canadian Militia Department. The War Office insisted on certain modifications for which the company demanded a month's extension of time, but by 7 April, 1915, not only were no deliveries made, but it was quite clear that the promised rate of output was not likely to be fulfilled. By 1 June, 1915, not one rifle had been submitted for inspection, and as the company were already occupied on a very large contract for the Canadian Government, it was proposed that the Dominion Government should

[1] N.Y. 1565, L. 2584, N.Y. 1616, L. 2674, N.Y. 1751, L. 2764, N.Y. 3115; 94/R/39. The rifle was to be similar to that manufactured at the Ilion factory except for an increased section of fore-end. Delivery was to be f.a.s. at New York. If by 1 May, 1916, the number promised were not delivered, the manufacturer agreed to instal machinery of a normal capacity of 1,000 rifles per day to bring the output up to promised rate.

[2] 94/R/29.

[3] HIST. REC./H/1142/1.

[4] Delivery was to begin at 200 per day, increasing to 300 in April, 1915. The sum of $350,000 was paid in advance, to be recovered by deductions of $3.50 from the price of each rifle ($34.00).

be asked to take over the rifle parts that had passed inspection, and also the liabilities of the company in respect of the sum advanced by the War Office.

The settlement of the question was left to the Ministry of Munitions.[1]

(c) ASSISTANCE TO RUSSIA.

The Russians were quite unable to meet their own requirements, and, in the early part of the war, rifles had been supplied by France, Italy, Japan and England,[2] but there was no question of manufacturing Russian rifles in England.

Negotiations were accordingly opened in the United States, and the Russian Government placed a certain number of contracts through their committee in that country, and payment for these rifles was made by the Head Artillery Department or out of American credits.

Occasionally the British and Russian Governments came into competition, as when the War Office hastened to anticipate the Russian Government in placing a contract with the Winchester Company.[3]

In England the question of Russian rifles was dealt with by a committee for the purchase of Russian supplies set up by Lord Kitchener, and although Messrs. Morgan were not the accredited agents of the Russian Government, contracts financed by the British Treasury on the basis of a special agreement between Lord Kitchener and the Grand Duke Nicholas, were placed in the United States by the British commercial agents. An order for 1,000,000 rifles was thus given to the Westinghouse Electric Manufacturing Company, and one for 800,000 rifles to the New England Westinghouse Company.[4] A third contract for 300,000 rifles was placed with the Remington Company of Ilion, but was cancelled before either delivery or payment had been made. These contracts were all placed for the standard Russian Mossin rifle of 7·62 mm. calibre.

(d) SITUATION IN JUNE, 1915.

On 1 June, 1915, there were in the hands of British troops 1,153,000 rifles, of which a certain number were non-effective, as being in transit, lost, etc., and in addition there were in the country 130,000 Japanese rifles, 150,000 emergency rifles and 130,000 drill pattern rifles. New rifles were coming in at the rate of 11,531 per week, plus 6,946 resighted and repaired. The total number of rifles available for issue weekly was thus 18,477, as compared with an average delivery of 8,409 per week in September, 1914, 9,743 in December, 1914, and 13,919 in March, 1915.[5] Deliveries were at the rate of 82 per cent. of contract promises in the case of the Birmingham Small Arms Company for the period January to May, 1915, and 64 per cent. in the case of the London Small Arms Company during the same time;[6] the Royal Small Arms Factory,

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[1] See below, Chap. IV. [2] HIST. REC./R/1420/18, Appendix C.
[3] See p. 11; N.Y. 1453.
[4] Memorandum by General Belaiew in D.M.R.S. 135 R.
[5] HIST. REC./R/1420/20. [6] HIST. REC./R/1400/3.

however, was making deliveries in excess of its promises. Delivery of American rifles, and from Messrs. Vickers, was expected to begin in the autumn.

At the end of May, 1915, after the arming of the first new army, there was a surplus of 55,000 rifles, which was 4,000 less than expectation, owing to the heavy fighting and the necessity for large reinforcements.[1]

The balance sheet as supplied by the War Office on 1 June was as follows :—

Income.

Available at outbreak of war ..		795,000
New Production :		
Aug.–Dec. 31, 1914 ..	113,000	
1 Jan. to 31 Mar., 1915	108,000	
1 Apr. to 31 May, 1915	87,000[2]	
		308,000
Received from Indian troops ..		50,000
		1,153,000

Distribution.

New Armies ..	172,000
Reserve Units ..	138,000
Depots, R.G.A., etc.	15,000
Territorials ..	80,000
Factory and other stocks, etc. ..	92,000
Expeditionary Forces	538,000
Wastage	118,000[3]
	1,153,000

The methods used by the Ministry of Munitions to maintain and increase these supplies are treated in the chapters which follow.

[1] Hist. Rec./R/172/17.
[2] Hist. Rec./R/1420/2 ; Hist. Rec./R/1000/10.
[3] Hist. Rec./R/1000/1.

CHAPTER II.

DEVELOPMENT OF BRITISH MANUFACTURE UNDER THE MINISTRY OF MUNITIONS.

(June 1915–December 1916.)

I.—Departmental Organisation.

On the formation of the Ministry of Munitions the responsibility for all supply was vested in the Director-General of Munitions Supply, Sir Percy Girouard, who was shortly afterwards succeeded by Sir Frederick Black. The administration of rifle supply with other munitions was entrusted to Mr. (later Sir Eric) Geddes, Deputy Director-General (C), and the section especially concerned with rifles was in the charge of Mr. G. M. Brown, and known as C.M.3.

Originally, it was arranged that the supply branch should only deal with articles which were difficult to obtain, the Contracts Branch placing orders direct in cases where the sufficiency and regularity of supply seemed assured.[1] In respect of rifles, the Contracts Branch dealt with accessories such as oil bottles, pull throughs, wire cutters and cleaning brushes, and this plan obtained until the end of 1917, when, to avoid overlapping or omissions, the supply of all accessories except textiles and chargers was undertaken by the supply branch. Other stores subsequently dealt with by the supply branch were signal pistols, bayonets, scabbards, swords, lances, and grenade dischargers.

In regard to the Royal Small Arms Factory, the control of which was temporarily retained by the War Office, Colonel Fisher, the Superintendent of Waltham and Enfield, was informed that Major Halse, the Assistant Superintendent, and himself were to be completely at liberty to give the Ministry expert advice and to report upon such matters as were required by the Ministry, but that, in order that the Master-General of the Ordnance might be kept in touch with such matters, copies of all reports and memoranda on specific subjects were to be sent to him.[2]

On 23 August, 1915, the bond between the Ordnance Factories and the supply branch was strengthened by the transfer of the former to the control of the Ministry of Munitions, and on 1 September a section known as C.M.7 was established by Mr. Geddes to deal with their administration. The Superintendent of Waltham and Enfield was thereafter fully responsible to the Ministry for the management, output, and satisfactory and efficient running of the factory.

All questions relating to salvage were referred primarily to a separate section, and inspection was carried on as before.

In October, 1915, Major Halse, while retaining his appointment and responsibilities as Assistant Superintendent at Enfield, took up

[1] D.D.G.E./E.M.3/429. [2] D.D.G.E./E.M. 1/40.

part time duty at headquarters for the purpose of developing the peddled scheme,[1] and on 28 December succeeded Mr. Brown as Director of C.M.3. At about the same time[2] he was also made Deputy Superintendent at Enfield with full responsibility to Colonel Fisher for efficient management and output. The great advantage of the combination of these two posts lay in the opportunity afforded for the closest co-operation between the various manufacturers and Enfield. Early in January the rifle section, together with those concerned with machine guns, small arms ammunition and the administration of Enfield, were transferred from Deputy Director-General (C)'s division to the general control of Mr. (later Sir Charles) Ellis, Deputy Director-General (D), and on 12 January, under a re-arrangement, passed over to Mr. (later Sir Arthur) Duckham, who had been appointed Deputy Director-General (E). Henceforward the rifle section was known as E.M.3, and that dealing with the Royal Small Arms Factory, E.M.4.

On 3 October 1916, Mr. Duckham resigned his post as Deputy Director-General (E) to take up the chairmanship of the Advisory Committee, and an Ordnance Supply Department was formed with Mr. C. Ellis as Director-General (D.G.O.S.) to deal with the supply of small and small arms ammunition, as well as guns and machine guns and the administration of the Royal Ordnance Factories. The office of Deputy Director-General (E) was then[3] taken over by Mr. Alexander Duckham who was responsible for rifles, small arms ammunition and machine guns, but the salvage section and E.M.4 were directly under the Director-General of Ordnance Supply.[4]

In May, 1917, as a result of an investigation and recommendations by the Organisation Commission, the section (E.M.4) dealing with the administration of the Royal Small Arms Factory was re-established under the control of Deputy Director-General (E). Colonel Halse, moreover, who had recently taken over the management of E.M.1 (machine guns, etc.) in addition to his other duties as Director of E.M.3, found his time so fully occupied that he could no longer carry on his work as Deputy Superintendent at Enfield. He accordingly resigned that office, becoming a full time member of headquarters staff as Assistant Deputy Director-General (E),[5] but continued, as being responsible under Deputy Director-General (E) for the output of rifles to the Ministry, to give Ministrial instructions as to the Enfield production and output. His post at the Royal Small Arms Factories was not filled;[6] but the manager, Mr. F. Carnegie, M.I.C.E., was appointed Assistant Superintendent. It should here be emphasised that the dual position of the Deputy Director-General, as officer in charge of rifle supply and as the authority responsible for controlling the Royal Small Arms Factory, had undoubted advantages. In particular it enabled the best use to be made of the Factory's skilled staff in organising trade supplies.

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[1] (Printed) *Weekly Report*, No. 12, II (16.10.15). See below, p. 18.
[2] The appointment was dated as from 1 January, 1916.
[3] 3 November, 1916.
[4] D.G.O.S./Enf./1.
[5] Departmental Office Notice (Whitehall Place) No. 36 (6.7.17).
[6] D.G.O.S./Enf./1.

For some while Deputy Director-General (E)[1] had been of the opinion that as the two factories under the control of the Superintendent of Waltham and Enfield were of so different a character,[2] and had grown so enormously during the war, and moreover, were administered by separate departments,[3] it would be to the advantage of the output of both if separate Superintendents were appointed. Advantage was therefore taken of the retirement of Colonel Fisher to divide the control, and Lt.-Colonel C. J. Newton of the Munitions Design Department was, on 8 November, 1917, appointed Superintendent of the Royal Small Arms Factory, to begin duty on 15 December.[4]

As a result of the re-organisation planned by Mr. Winston Churchill in the autumn of 1917, the rifle section was attached to Group "G" with Sir Glynn West as Council Member, and Mr. Duckham became Controller of the Small Arms and Machine Guns Department (C.S.A.M.G.). In February, 1918, Groups "P" and "G" were amalgamated to form Group "O," of which Sir James Stevenson was Council Member.

In November, 1917, Mr. Duckham had resigned his appointment as Controller of Small Arms and Machine Guns, and Colonel Halse, who had been acting as Deputy Controller, became, as from 15 February, 1918, Controller of the department.

An important feature of the Ministry's organisation for supply was the appointment of progress officers, or "quantity" inspectors, who visited manufacturers and acted as a link between contractors and the department.[5]

II.—Development of Home Supply, June-December, 1915.

The total War Office requirement for the period August to December, 1915, was for 584,000 rifles, of which 200,000 were wanted in August to September, 216,000 in October and November, and 168,000 in December. Of this number 300,000 were to equip new troops, and 284,000 allowed for wastage.[6] This demand was not likely to be met from home sources, but with the American deliveries to begin in the autumn of 1915, the rifle situation was so much better than the machine gun position that the Birmingham Small Arms Company's rifle plant extension (representing 4,000 rifles a week)[7] was transferred to machine guns.[8] To offset this loss and to increase and expedite supply the following steps were taken.

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[1] Proposals were put forward on 28 February, 1916 and 13 August, 1917.

[2] The work of the Royal Gunpowder Factory was entirely chemical; that of the Royal Small Arms Factory entirely mechanical.

[3] The administration of the Royal Gunpowder Factory was transferred to the Explosives Supply Department on 14 January, 1916.

[4] C.R./D.G.S.G./2512.

[5] See below, p. 62.

[6] Figures given by Major Byrne in a minute to the Director-General of Munitions Supply. Wastage was calculated at the rate of 12 per cent. per month on the total strength less 25 per cent. to 33 per cent. for return of repairable rifles, leaving a net wastage of about 100 per cent. per annum. (Hist. Rec./R/172/17; 1420/20.)

[7] See above, p. 6.

[8] Vol. XI, Part V, Chapter II.

(a) THE PEDDLED SCHEME.

The War Office conference of 9 June, 1915,[1] bore fruit in a comprehensive scheme possessing three more or less distinct features. In the first place, the possibilities of co-operation between existing rifle factories, so as to produce additional rifles by associating surplus material, machinery or components, were discussed by the sub-committee appointed at the conference,[2] and two parts of the scheme for using the resources of the trade were developed separately by the department and especially by Mr. Brown, the Director of C.M.3. One object was to obtain large supplies of particular components from non-rifle-making factories, and then to turn over the machinery actually manufacturing these at rifle factories to the manufacture of the more difficult components. This proved impracticable owing to difficulties in constant change of work, machinery and labour. To begin with, the backsight bed was selected for experiment as being comparatively easy to make, and because a good deal of the machinery used for this component at Enfield would be useful towards arranging for an increase in the output of bodies. A number of contracts were placed, but it very shortly appeared that this plan would not be a success, as there was no guarantee that any manufacturer would make good, and until it seemed likely that large supplies would be forthcoming, it would be useless to manufacture fixings and to order the machinery needed to make up complete units for the production of the more difficult components. Unless, therefore, preparations were to be made on the off-chance of success which appeared doubtful, besides involving the employment of skilled labour which was most difficult to obtain, the time occupied in transferring the machinery to the manufacture of the difficult components would actually be longer than that taken in laying down new plant.[3] This plan, therefore, was not further developed at the time.

The other object in view was the production of rifles by farming out components among the non-rifle manufacturers, and the original intention in regard to major components was to collect in different parts of the country groups of machinery for their manufacture, and to provide at Enfield a new shop for assembling. This scheme, which was intended to be self-supporting and quite independent of the rifle-making factories, was known as the "peddled scheme," and on 25 June, 1915, Mr. Lloyd George gave authority to place orders for rifle components with engineering firms.[4]

The factory of the Standard Small Arms Company[5] was in the first instance the backbone of the proposals in connection with this scheme. It had become apparent that the company, in spite of every

[1] See above, p. 9.

[2] Their recommendations were given practical effect in the rifle component pool scheme. See p. 20.

[3] HIST. REC./R/1400/21.

[4] It is noteworthy that this had been the normal method of manufacturing small arms until the introduction of machinery for the manufacture of the Minié Rifle about 1850-1860. (*Select Committee on Small Arms, Parliamentary Papers*, 1854).

[5] See above, pp. 7–8.

assistance and encouragement, would never produce complete rifles,[1] and arrangements were accordingly made to cancel the existing contract so far as concerned the manufacture of complete rifles and to substitute orders for four major components, viz :—the body, with guide charger ; the bolt and bolt head ; the nose cap ; and the trigger guard.[2] The company were to produce 1,500 sets of components a week, ultimately increasing to 4,000 weekly when new machinery was delivered.[3] Efforts to make similar arrangements with other factories failed, and after much consideration[4] it was decided that the bayonet shop at Enfield should be dismantled as such, and that additional machinery should be obtained to produce there a further 3,000 sets weekly of bodies, bolts and nose caps, while trigger guards corresponding to the Royal Small Arms Factory production were to be made by the Singer Manufacturing Company.[5] The manufacture of the additional bayonets required was then entrusted to the Wilkinson Sword Company and to Messrs. Sanderson Bros. and Newbould of Sheffield.[6] The conversion was expected to take from eight to nine months.

Regarding the other components, orders were placed with many firms, and Mr. Brown endeavoured to make arrangements, based on promises of deliveries, which would have exactly fitted in and ensured delivery of the right number of components per week to complete the rifles for which he anticipated he would be able to obtain the major components. Contracts were placed with firms of very varied pre-war experience, and, as time went on, in addition to the gunsmiths, such firms as the British United Shoe Machinery Company Ltd., Jones's Sewing Machine Company, the Wolseley Sheep Shearing Machine Company, the Chubb & Sons Lock and Safe Company, Messrs. Riley, billiard table makers, and Messrs. Linley, manufacturers of railway lamps and similar stores, as well as manufacturers of motor and cycle fittings, of railway door catches, of lace machinery, and of clocks and watches, were employed on component making.

The main disadvantage in the scheme was that it allowed only for the exact number of components needed. The pace of rifle manufacture was thus regulated by the deliveries of certain minor components, which were being manufactured by inexperienced makers. Meanwhile the experienced rifle-makers had surplus capacity for certain components lying idle, and were anxious to extend their capacity at the expense of the State by levelling up their plant to produce complete rifles. Colonel Halse, on his appointment as Director of C.M.3, set to work to enlarge the whole scope of the peddled scheme, so as to secure greater co-operation between the rifle-making factories and the component manufacturers with a view to making the fullest possible use of surplus output, especially that of Enfield. The scheme, as

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[1] Sec./R.S./135.B/1.

[2] HIST. REC./R/1400/21.

[3] 94/A/353 signed 18th October, 1915. Up to £100,000 secured by debenture was advanced for plant.

[4] A meeting was held on 18th September, 1915, to discuss thoroughly the extension of the peddled scheme. (D.D.G.C./C.M.G./123.)

[5] 94/G/4506.

[6] (Printed) *Weekly Report* No. 11, II (9.10.15).

revised early in 1916, was known as the Rifle Components Pool. It embodied the main features of the three more or less separate schemes of June, although the inexperience of private firms still made it impracticable to stop entirely the manufacture of any special components at Enfield.

The "pool" took every component which the rifle-makers could produce in excess of their production of complete rifles, and all the components similarly manufactured at Enfield, as well as all the major components which the Standard Small Arms Company could turn out, and the whole of the production under the peddled scheme. The spare capacity of the experienced rifle-makers was thus utilised and their opposition to the peddled scheme allayed. The pool provided a source of supply not only for the production of new weapons but also for the spare parts required by the Chief Ordnance Officer.[1] A considerable stock of components was also built up, so that should the Royal Small Arms Factory or one of the contractors run short of any particular component, the pool was drawn upon and delay avoided. This was continuously done by the London Small Arms, and sometimes by the Birmingham Small Arms Company. In the case of the Royal Small Arms Factory, the pool, being available on the spot, was used as required to enable machines to be transferred to other components, but only in the case of small components, and never in the sense of transferring machines for the manufacture of major components as was originally intended.

In estimating the number of components to be contracted for, Colonel Halse based the percentage of each component on actual experience of repair work done at Enfield, and worked on the possibility of obtaining 200,000 rifles by the end of 1916. It was found impracticable to get the manufacture of any further supplies of the major components begun sufficiently early to ensure delivery before the late spring of 1917.

The contractors were visited continuously, and progress was reported to be satisfactory, though output was likely to be disappointing unless more skilled labour was forthcoming.[2]

(b) The Royal Small Arms Factory.

The extension of the factory to a capacity of 12,000 rifles a week or, alternatively, the erection of a new factory at Enfield or elsewhere with a capacity of about 8,000 rifles a week was considered,[3] and on 25 June, 1915, Mr. Lloyd George assented to the preparation of estimates. The possibility of manufacturing the pattern 1914 rifle on the ground of its greater simplicity was again discussed, and negotiations for a complete rifle plant from America were opened,[4] but the terms offered were declined.

A considerable number of machines however were obtained to increase the capacity of the Royal Small Arms Factory; and although

[1] Hist. Rec./R/1400/21.
[2] (Printed) *Weekly Report*, No. 15, II (6.11.15).
[3] O.F./Gen./039; Hist. Rec./R/1420/10.
[4] Cables L. 6218, N.Y. 6663, L. 8294.

only half the amount of plant ordered had been received,[1] the output had in September reached the maximum ordered by the War Office,[2] and was expected shortly to be at the rate of 7,000 rifles a week.

(c) MESSRS. VICKERS (CRAYFORD).

At the time of the formation of the Ministry, Messrs. Vickers had under construction a factory for the manufacture of Serbian rifles. It was decided to use these works for the manufacture of British rifles, and although final negotiations with Serbia had not been completed on 3 August, 1915, Mr. Lloyd George then authorised the conversion of the factory. Delivery of rifles under the War Office contract had not begun,[3] but with the additional plant was promised at the rate of 3,000 a week from about the middle of 1916.

(d) ADDITIONAL RIFLES.

On 6 July, 1915, Mr. Lloyd George sanctioned the purchase of 1,000,000 rifles in addition to those already ordered, for delivery by the end of 1916 if possible, and any approved pattern was to be allowed. Various attempts were made to purchase "spot lots" offered for sale by various individuals and companies. The Ministry met with difficulties similar to those already experienced by the Admiralty and the War Office. For instance, in July 300,000 Krag Jorgensen rifles were reported as obtainable "from a reliable source," and after many cables and much investigation it appeared that these rifles which had been offered for sale by a number of different people were obsolete rifles, the property of the United States Government and safely stored in a Government Arsenal. Similarly, an offer of 200,000 new French Mausers all ready for delivery "from reliable people" failed to materialise and negotiations with a South American firm came to a sudden end when that firm was requested to communicate with Messrs. Morgan. A case of rifles detained from a neutral ship proved to be of American Boy Scout pattern destined for sale in Scandinavia.[4]

Meanwhile, negotiations conducted in the United States by Messrs. Morgan and Mr. D. A. Thomas resulted in the placing of orders for 1,100,000 additional rifles with firms which had already undertaken contracts for the British Government.[5]

(e) POSITION ON 31 DECEMBER, 1915.

Before the end of the year it became apparent that some of the sources of supply on which reliance to meet requirements had been placed were not likely to come up to expectation. Messrs. Vickers (Crayford) whose contract for ·303-·276 in. (*i.e.*, pattern 1914) rifles should have brought deliveries in October, 1915, reported that they could not begin until April, 1916, and a visit of inspection revealed a

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[1] O.F./Gen./039.

[2] (Printed) *Weekly Report* No. 6, III (4.9.15).

[3] See above, p. 7.

[4] 94/Gen. No./134.

[5] See below, pp. 42–43.

most unsatisfactory state of affairs.[1] Moreover, the delivery of American rifles which was due to begin in the autumn had not started, although the outlook for the future was considered hopeful.[2] The Birmingham Small Arms Company also reported that owing to the late delivery and unsatisfactory nature of the plant ordered from America their promised increase to 8,000 rifles a week would be delayed. The London Small Arms Company were in difficulties owing to indifferent organisation and labour troubles; they had been unable to keep contract dates, and their trading for the year ending 31 March, 1915, had resulted in a serious loss.[3] It was, however, considered necessary in the public interest not to cut off this source of supply, which produced about 1,500 rifles a week, and Treasury sanction to cover the deficit, which was ascribed to the payment of additional wages, was obtained.[4] Existing contracts were cancelled and a new agreement was made on 12 November, 1915, whereby the company were to supply 50,000 rifles at 85/- each, delivery to be at the rate of 1,600 a week increasing to 2,000 by the end of January, 1916. The day work rate was fixed at 55 per cent. of delivery due or invoiced in any one week.[5]

In regard to the peddled scheme, while the supply of major components and barrels gave cause for no little anxiety, no difficulty was anticipated in getting a sufficient supply of other components to meet requirements for 1916 and 1917.[6]

The percentage of deliveries to estimates had, during the last half of 1915, increased to about 85 per cent. in the case of the Birmingham Small Arms Company, and to about 74 per cent. from the London Small Arms Company,[7] and although the figures for October showed an excess of 2,681 over the original estimate as made in June, 1915, and of 5,681 over the estimate revised when it became necessary to discount the output of Messrs. Vickers (Crayford),[8] the actual output by the end of the year did not cover the War Office demand, and the outlook for 1916 and especially the early months of that year was sufficiently serious.

III. Development of Home Supply, January–December, 1916.

The situation, however, turned out much more favourably than was expected, chiefly owing to the fact that the net wastage, instead of being about 100 per cent. a year was between 20 per cent, and 30 per cent. and also because it was decided to equip all except regular divisions, which were armed at the rate of 18,500 rifles per division, with only 15,500 per division as against the 17,000 on which the estimates had been based. If wastage had been as great as was expected

[1] (Printed) *Weekly Report*, No. 6, III (4.9.15).
[2] (Printed) *Weekly Reports*, No. 10, II (2.10.15); No. 14, II (30.10.15).
[3] *Ibid*. No. 6, III (4.9.15); No. 11, II (9.10.15).
[4] 94/R/192; HIST. REC./R/1420/8.
[5] 94/A/365; 94/R/381.
[6] HIST. REC./R/1400/21.
[7] Figures to October only. HIST. REC./R/1400/3.
[8] (Printed) *Weekly Report* No. 15, II (6.11.15).

there would hardly have been any surplus during the last five months of 1915 for new equipment. It was, however, found possible to equip in all over 70 divisions at the reduced number of rifles per division.[1] On 6 January, it was reported that there was a surplus of 235,000 rifles from home production alone, so that although very few of the new units of the new armies, as distinct from units providing drafts who were ready to take the field, were equipped with rifles,[2] the situation was at least as far advanced as that which was contemplated by the War Office in formulating their requirements.[3] The balance, therefore, of rifles not supplied during 1915 was dropped and the requirement for January to December, 1916, remained as fixed on 31 August, 1915, at 2,472,000 rifles, of which 600,000 were required to equip divisions in the field, 600,000 for reserve, and 1,272,000 to meet wastage.[4] Of this number it was estimated that home production would supply about one million, leaving about one and a half millions to be supplied from the United States, as by this time the Ross rifle was discounted as a source of supply,[5] but as the American deliveries during the year were expected to exceed 2,500,000 rifles, it seemed as if rifles had been considerably over-ordered. In fact, early in January, the question of handing over to Russia 500,000 rifles, or, alternatively, of cancelling part of the American order was engaging the attention of the Army Council.[6]

The Ministry of Munitions, indeed, taking into account the reduction of the rifle strength of a division and basing probable wastage upon actual 1915 figures suggested a reduction in the 1916 requirement,[7] but the War Office, while reducing the wastage estimate to 750,000, maintained their demand at the original figure "to meet unforeseen demands from Colonial contingents, India, etc., and in order to provide a safe margin to cover abnormal expenditure."[8]

By February, 1916, the arrangements made to strengthen British supply were so full of promise that Deputy Director-General (E) expected the whole of the British requirements for 1917 to be met from home sources, and the possibility of allocating the whole of the American output for 1917 to Russia was receiving serious consideration.[9]

(a) Measures to Stimulate Supply.

The most important work of the Ministry at this period and onwards was not so much the making of new contracts, but rather the assisting of firms by arranging supplies of material and labour for them, and also by helping them with advice and close but friendly criticism. Early in 1916 the headquarter staff was strengthened by the appointment of engineers with special knowledge of manufacture to very close limits and of reproductive work, such as the production

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[1] Hist. Rec./R/1420/20. Hist. Rec./R/1141/6.
[2] Hist. Rec./R/1420/2.
[3] Hist. Rec./R/1420/1.
[4] Hist. Rec./R/1420/1.
[5] See below, p. 53.
[6] Hist. Rec./R/1420/1; 57/Gen. No./4622.
[7] Hist. Rec./R/1420/1.
[8] 57/Gen. No./4622. Copy filed in Hist. Rec./R/1420/1.
[9] For the Russian supply, see below, pp. 38–39.

of boot machinery. These officers acted in an advisory capacity towards the trade generally, and they conveyed to the makers of rifles or components much of the experience gained from Enfield. The control of the Royal Small Arms Factory by the officer in charge of rifle supply served a similar purpose.

In connection with the further development of the rifle component pool, it was found advisable to deal more largely with the scheme from Enfield rather than to try to arrange for a very much increased output from the trade. The increase of body and barrel plant was the earliest concern of the Department.

The main step taken to improve the barrel position, which was far from satisfactory, was the extension of the Royal Small Arms Factory barrel shop so as to produce from 4,000 to 4,500 additional barrels per week.

With regard to the output of complete rifles, all three factories were producing an increasing weekly supply, and the total at the end of February was over 17,000 rifles a week.

(*b*) Effect of Non-Delivery of American Rifles.

The hope that American contractors would, early in 1916, make good on their orders was fated to disappointment, and when on 7 March, 1916, the Army Council complained that "the training of troops and augmentation of the forces in the field are seriously hampered by the deficiency in rifles," and asked "when any improvement in the rate of supply may be expected,"[1] the reply was that the "discrepancy between the present estimate for the early months and those previously forwarded is entirely due to the failure on the part of American contractors to commence delivery by the dates promised."[2] In addition to the units kept back for lack of rifles, there were still several units in the field armed with long rifles who were to be re-armed as soon as possible,[3] urgent demands had been received from India,[4] and by 11 March, 1916, only 34 American rifles had been received for inspection.[5] In April the estimate of deliveries during 1916 was some 560,000 rifles less than that of the most conservative estimate calculated in the previous February;[6] but to an enquiry as to whether special efforts should not be made to obtain an increase of approximately 30 per cent. in the British rifle output by the end of the year, the Director of Artillery replied that although American rifles were to be used with garrisons, home defence units and national volunteers, it was not proposed to equip any troops in the field with them, and that although an additional supply of British rifles would be useful immediately, it would probably not be required in eight months' time when the increased output might be expected to begin.

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[1] 57/Gen. No./4622.
[2] D.M.R.S./135.
[3] (Printed) *Weekly Report*, No. 32, II (4.3.16).
[4] See below, p. 40.
[5] (Printed) *Weekly Reports*, No. 23, II (1.1.16); No. 33, II (11.3.16).
[6] For details of the American contracts history see Chap. IV. The figures given on 22 November, 1915, were 2,667,800, on 15 February, 1916, 1,913,450, and in February, 1916, by Major Smyth Piggott 1,529,500, and in April, 1916, by Mr. Moir 969,507.

The foresight already exercised by the Minister in ordering in advance large numbers of munitions had proved to be of such great value that it was decided not to deviate from the existing policy, and on 10 May, 1916, the Minister stated that every effort was to be made to increase the home supply of rifles.[1]

(c) POSITION IN REGARD TO HOME SUPPLIES, MAY, 1916.

Meanwhile, although with some 1,390,000 rifles in existence in January, 1916, plus an estimated income during 1916 of 976,000 from British and 970,000 from American sources, there would be a surplus of only 224,000 rifles to meet the estimated wastage of 750,000, it appeared not unlikely, after taking into account previous wastage, that the surplus would cover the actual losses, but even if the prospect for the end of the year and after was hopeful the situation during the first six months was really serious, and the supply was never equal to the demand.

In connection with the rifle component pool, it had soon become evident that probably not more than half the expected number of rifles would be produced during the year. The income of components was carefully watched and balances were drawn out. Visits to the Standard Small Arms Company revealed the fact that the delivery terms of the contract would not be approached. An opportunity was taken, in consequence of the large number of machines which were not being used, of borrowing some to assist the output of the Royal Small Arms Factory which was being held up on account of the non-delivery of machines on order. Somewhat later the manufacture of bolts, bolt heads and nose caps was transferred to other firms while the company continued to make bodies and trigger guards. Just about this time the contract with Messrs. Vickers for pattern 1914 rifles had been abandoned as the company failed altogether to produce rifles, and judging from results obtained by them in respect of components which they made for rifles, it would have been many months after the date of cancellation (6 July, 1916) before output could have begun,[2] and it was considered that the best plan would be to arrange for the transfer of a certain number of machines to Crayford with a view to producing the components there. The committee, however, which had been appointed to consider the matter reported so unfavourably on the prospect of obtaining delivery that the scheme was abandoned and the machinery so released was sent to Enfield, so that with necessary additions the output of components there could be brought up to the necessary amount to cover not only the whole of the rifles for which the Royal Small Arms Factory was manufacturing the major components but also all those for which the Standard Small Arms Company would make bodies.[3] Even so, the company did not attain an output of 2,000 bodies a week until April, 1917, and within the first two years of the original start only 5,000/6,000 had been produced.[4]

The failure of this company to turn out the major components caused great delay in the delivery of complete rifles, and in June

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[1] HIST. REC./R/1420/23.
[2] Sec./R.S./135 B/1.
[3] HIST. REC./R/1400/21.
[4] Sec./R.S./135.B/1.

Deputy Director-General (E) reported that the scheme had not come up to expectations.[1] The first set of peddled rifles was not delivered till 8 July, and although progress thereafter was fairly steady, reaching about 1,000 rifles a week in October, the maximum of 7,000 rifles a week was not likely to be realised until April, 1917. In point of fact this maximum was never actually reached.

The manufacture of the wooden components by the Birmingham Small Arms Company and other firms had not developed in accordance with expectations. For instance, whereas it had been thought that output from the Birmingham Small Arms Company would begin by the end of February or March, the company did not find it possible to begin delivery of butts until May and of fore-ends until October, and the contract for the former at only 500 a week to increase to 3,000 as soon as possible was not signed before 4 May, 1916,[2] and that for the latter at 1,000 a week increasing to 3,000 by 1 January, 1917, was not placed until 23 October.[3] Meanwhile, to meet the demand a new wood component shop had to be erected at the Royal Small Arms Factory.

The component pool was, however, of constant use as a means of assisting production. The trade rifle factories frequently drew components from the pool, as did also the Royal Small Arms Factory. The London Small Arms Company, for instance, drew barrels from Enfield and from Messrs. Vickers' works at Crayford and numerous other components. A successful arrangement was also made with this company on the lines of a mess wine-cellar scheme. The department deposited a stock of components at the company's works for use as they were wanted, taking stock of what was left at regular periods.

(*d*) THE INCREASE IN WAR OFFICE REQUIREMENTS, AUGUST, 1916.

In July, owing to the Russian refusal of the American rifles,[4] and in view of the fact that in 1917 an income of new British rifles at 104,000 per month and repaired at about 25,000 a month should more than meet requirements,[5] the question of cancelling about two and a half million American rifles was brought forward, but after some correspondence, the whole position was altered when on the 15 August, 1916,[6] the War Office increased their rifle demand to 3,125,000, viz., an additional 653,000 by the end of the year, of which 2,550,000 were for new equipment and 575,000 to meet wastage. It was quite impossible for this number to be supplied by the end of the year, and although by November the home rifle output had reached approximately 20,000 new

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[1] (Printed) *Weekly Reports*, No. 46, V (17.6.16); No. 48, V (1.7.16).

[2] 94/S/1722. Price 3/1 each with stock bolt washer. Owing to an alteration in pattern, front and rear hand guards were not required. A contract was therefore placed on 17 May, 1916, for 6,500 only of each.

[3] 94/S/1722. Price 6/8 each with screwed pin.

[4] For the supplies of rifles to Russia, see below, pp. 38–39.

[5] Statement of small arms position on 20th July, 1916 (HIST. REC./R 1420/20.).

[6] 54/Gen. No./2356.

rifles a week, and with existing plant was expected to attain to 26,000 a week by April, 1917, the deficit was likely to amount to over a million rifles.

In view of the uncertainty of the American rifle situation it was evident that to meet the new requirements the home production would have to be further increased; but owing to the difficulties of erecting new plant and obtaining labour, many months would elapse before any increased production could be expected, and as the equipment of troops would consequently be delayed, it appeared that the wastage allowance,[1] already in the opinion of the Ministry sufficiently excessive, could reasonably be reduced, more especially as it was understood that the additional rifles were to be used to some extent for the arming of troops not engaged in any theatre of war and in respect of whom there should be but little wastage. A letter was accordingly sent to the War Office,[2] and in reply the Ministry was instructed not to arrange for any further increase until further information as to the prospects of the supply of rifles from America was available.[3]

Meanwhile, as a result of an agreement made with the American firms on a "no profit, no loss basis,"[4] it became reasonably probable that the quotas arranged could be produced by about the middle of 1917, or at least by the end of that year.

(e) SITUATION AT THE END OF THE YEAR.

By the end of the year 1916, acceptances from all sources were only just over one and a quarter million rifles[5] as against 3,125,000 demanded, thus leaving a considerable deficit to be made good in the following year. The prospect, however, was not serious. The regular output, without peddled rifles, was approaching 20,000 a week,[6] and there was every reason to suppose that reliance could be placed on the peddled scheme to produce a steady increase to 4,000 rifles a week, with a possibility of reaching 7,000 a week if required. Even in August, before the amended requirement was received, it had got to be abundantly clear that the rifles produced in this country would be sufficient not only to equip new troops but to maintain troops in the field and to cover wastage at the front not only in the kind of warfare then adopted but if an advance was made into the open.[7] The American deliveries for 1916 had fallen far short even of Sir Ernest Moir's estimate, and their output for 1917 was needed chiefly to cover the deficiency caused by the amended requirement and for shipment to Allies and Colonial and Indian troops as required.

[1] 1,300,000 for the period August 1916 to December 1917, as compared with a net wastage of 480,000 rifles for the first two years of the war.

[2] 3rd November, 1916. D.M.R.S. 135.

[3] 54/Gen. No./2356.

[4] See below, pp. 50–51.

[5] HIST. REC./R/1000/2; Enfield 418,283; Birmingham Small Arms Co. 435,212; London Small Arms Co. 99,433; Canada 33,476; U.S.A. 373,282.

[6] Enfield 8,650; Birmingham Small Arms Co. 9,000; London Small Arms Co. 2,000.

[7] HIST. REC./R/1420/17.

The component pool was developing well and the income of all components was carefully watched throughout the year. Balance sheets were drawn out at first at irregular intervals, and from October onwards at each quarter.

With the help of additional machinery, extensions to shops and extra facilities to relieve congestion and help transport, such as the construction of a new railway siding, the capacity for rifle output at the Royal Small Arms Factory was considerably increased, and the maximum capacity for complete rifles was fixed at 8,500 per week which was approximately correct. All rifles above this number were to a certain extent dependent upon components manufactured by the trade, although up to 10,000 a week the factory drew very little from the pool. All rifles produced beyond 10,000 a week were largely made of peddled components.

The Birmingham Small Arms Company had reached an average of 9,000 rifles a week, and were capable of further increase, and during this year the London Small Arms Company in spite of accidents and much sickness reached their maximum output. In the autumn, owing to difficulties with sub-contractors, the company erected their own screw-making machines and were thereby enabled to speed up output. In the course of the year two further contracts had been placed with the company, one on 2 March, for 70,000 rifles at 84/10 each, delivery to begin on 4 May, 1916,[1] and another on 3 October for 26,000 rifles or as many more as could be produced by 31 March, 1917, at 84/8 each, delivery beginning on 4 January, 1917.[2]

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[1] 94/R/457. The reduction in price was due to the omission of certain details at 1/5 per rifle, and the addition of 1/3 to meet the increased price of stocks. The price was also subject to reconsideration in the event of the price of fuel rising beyond 10 per cent. after 30th June, 1916, and any increase in wages after 28th January, 1916, providing such increases were approved by the Minister of Munitions.

[2] 94/R/933. The revised price was made up as follows :—additional 3d. on price of stocks less 5d. per rifle due to omission of wind gauge and substitution of cap backsight.

CHAPTER III.

HOME MANUFACTURE FOR THE BRITISH AND ALLIED FORCES, 1917–1918.

I.—Maintenance of the Home Supply, 1917–18.

(a) THE WAR OFFICE REQUIREMENT FOR 1917.

The War Office requirement for January to December, 1917, was given as 1,000,000 rifles, all needed to cover wastage,[1] and, in addition, 800,000 pattern 1914 rifles from America,[2] plus about 60,000 extra for spares.[3]

The American total was apparently based on the supposition that the output from home sources would not exceed an average of 22,000 rifles a week, but the Ministry was confident that as, so far as could be judged, there was sufficient rifle-making machinery in the country to meet all requirements and as the rifle-making factories were nearing their maximum output, unless some difficulty which could not be foreseen presented itself, the total rifles produced in Great Britain during 1917 would exceed the number indicated by at least 100,000: a number sufficient to cover losses which might occur in connection with the shipment of the American rifles and to meet any other contingency which might arise.[4] Colonel Halse, therefore, hoped by keeping well up to programme to establish such confidence as would enable the Army Council to reduce their demand for American-made rifles.[5]

Arrangements were in progress for the storage or sale of the plant which under the amended contract terms was to become the property of the British Government,[6] and for the shipment of parts to cover manufacture of spares in England. Among other suggestions Colonel Byrne had pressed the desirability of establishing another rifle plant, but in view of the premier importance of machine gun manufacture, the proposal was set on one side.[7]

(b) SUCCESS OF HOME PRODUCTION.

With the declaration of war by the United States and the sale of the factories in that country to the Government[8] after a total of 1,243,565 American rifles had been accepted, it became necessary for home production to meet all calls. As Colonel Halse had hoped, the British rifle factories were fully equal to the demands made upon them.

By 12 May, 1917, the weekly output from all sources had reached 25,000 rifles, towards which the Royal Small Arms Factory had contributed 10,500, with 2,500 from Standard Small Arms bodies. The London

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[1] 54/Gen. No./2356. [2] *Ibid.*
[3] D.D.G.E./E.M.3/359.; 54/Gen. No./2356; D.D.G.E./E.M.3/495.
[4] D.D.G.E./E.M.3/359; D.D.G.E./E.M.3/495.
[5] D.D.G.E./E.M.3/377. [6] See below, p. 51.
[7] D.D.G.E./E.M.3/338. [8] See below, p. 52.

Small Arms Company maintained an output of about 2,000 rifles a week, and in April the Birmingham Small Arms Company reached their maximum output of 10,000 rifles a week. The need, however, for increasing the supply of machine gun spares from this factory led to a decision that this figure was not to be maintained, and the future average was about 9,500 rifles a week.[1]

The high output was not maintained. The engineers' strike affected actual output and stopped the natural increase, so that 3,798 rifles were directly lost and indirectly a far larger number. Normal output of 25,000 was not again reached until the end of June, and not steadily until the latter part of July.[2] Other hindrances were a fire at the British Gun Barrel Company's works, which necessitated the arrangement of a supply of some 700 barrels a week to the London Small Arms Company from another source, and continual troubles experienced by the London Small Arms Company with material and labour.[3]

It became quite safe to say that the requirement would be fully met with a surplus, and that if the manufacture of peddled rifles were continued at the maximum rate of output which that scheme was arranged to produce, the output at the end of the year would be 26,000/27,000 rifles a week.[4] By 15 December the actual deliveries were over 26,000 rifles of which 11,700 were turned out by the trade, 11,000 from Enfield and 3,300 made from Standard Small Arms bodies : a result attained in spite of the fact that during the autumn the inspection both in the factory and by the Inspection Department had been tightened up.[5]

During the early part of 1917, the Standard Small Arms Company were in financial difficulties, and in order to secure the continued supply of components from this firm another loan was made. The alternatives of calling in the Birmingham Small Arms Company to re-organise the shops or of foreclosing and putting in a government manager were rejected, the former as being likely to cause delay in output and to add to the expense of production, and the latter as being likely to dishearten the firm and stop production when it could ill be spared.[6]

Owing to the very long delay in the production of the major components, arrangements had been made by which stocks of some of the minor components were obtained, thereby avoiding the necessity of reaching such a high weekly output in the case of these components as would have been necessary had the whole of the contractors been in a position to start the delivery of components at the same time. So that plans might, therefore, be laid for the 1918 output of these minor components, the War Office were asked to indicate their requirements for the coming year, and on 18 June, 1917, the number needed for the

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[1] (Printed) *Weekly Reports*, No. 88, V (21.4.17) ; No. 92, VII (19.5.17) ; No. 93, VII (26.5.17).
[2] (Printed) *Weekly Reports*, No. 95, VII (9.6.17); No. 97, VII (23.6.17) ; No. 101, VII, (21.7.17).
[3] (Printed) *Weekly Reports*, No. 94, VII (2.6.17).
[4] D.D.G.E./E.M.3/559.
[5] (Printed) *Weekly Reports*, No. 119, XI (24.11.17) ; No. 122, XI* (15.12.17).
[6] D.D.G.E./E.M.3/377.

period 1 July, 1917, to 30 June, 1918, was given as 1,200,000 rifles. The estimated output of at least 100,000 new rifles a month on which the War Office were basing their calculations would, so far as could be foreseen, be required for provision and maintenance, and even should 1,440,000 rifles be supplied during the year, it was considered that only a small balance would be left over to meet unknown contingencies. The Ministry was, therefore, asked to work up to the maximum output which could be arranged.[1]

(c) SCHEMES FOR REDUCING OUTPUT.

The number of acceptances still advanced, and early in October it became necessary to consider the entire position regarding rifle supply. The output from the rifle-making factories alone, which during the quarter ending 30 September had amounted to 313,000 rifles, was for the future expected to average 23,000 a week,[2] and with the addition of rifles made from Standard Small Arms bodies was already more than sufficient to meet War Office requirements. With normal growth and without renewing the contract with the Standard Small Arms Company for bodies, a surplus of 60,000 rifles by June, 1918, and an estimated total output of 1,166,000 rifles between 1 July, 1918, and 30 June, 1919, seemed assured, and, in view of the fact that very few new units were to be armed during 1918 and 1919, it appeared that some of the plant might be better employed on other manufacture.

An arrangement had been made with the Birmingham Small Arms Company, whereby they were to reduce their rifle output by 2,000 a week so as to allow for an increase in Lewis gun manufacture, but in consequence of a reduction in the demand for Lewis gun barrels and some other alterations, the firm found that they were in a position both to produce the additional Lewis guns and to maintain their rifle output. At the same time the company stated that any further increase in guns at the expense of rifle output would be a most uneconomical proposition and one which would take many months to arrange.[3]

Attention was, therefore, turned to the Standard Small Arms Company. It was fully appreciated that, if no further contract for rifle bodies was placed with them, the organisation of the plant would be broken up and that it would not be practicable, except after great delay, to get the plant working again, but the Minister was anxious that no plant should be employed on the manufacture of any munitions which were likely to be over and above the requirements of the Army Council, and as a reduction in the number of rifles produced from Standard Small Arms bodies involved the least amount of dislocation, the War Office expressed their concurrence in a proposal not to renew the Standard Small Arms Company's contract, and, although unable

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[1] D.D.G.E./E.M.3/559.

[2]

Royal Small Arms Factory ..	11,500
Birmingham Small Arms Co. ..	9,500
London Small Arms Co. ..	2,000

[3] D.D.G.E./E.M.3/672.

to give exact numbers for the period 1 July, 1918, to 30 June, 1919, intimated that 1,166,000 rifles would probably be sufficient to meet requirements.[1]

In November the question was raised again and the statement of probable requirements for the last half of 1918 was given by the Assistant Director of Artillery as 583,000 rifles. Colonel Halse thereupon informed the War Office of his intention to lay plans to continue the production of rifles at approximately 100,000 a month until 31 December, 1918, unless notification to the contrary was received.[2]

For the re-employment of the Standard Small Arms Company's plant, various suggestions were under consideration, such as the utilisation of a portion to assist in the production of spares for artillery guns or its removal to form a nucleus towards the plant of a new machine gun factory,[3] but the scheme never materialised, owing to a further increase in the machine gun requirement. To meet this, the Birmingham Small Arms Company were instructed to increase their machine gun output, and to arrange for a gradual reduction in rifle output by 500 a week to 6,000 a week by July, 1918.[4] No advantage was anticipated from a more rapid reduction than this. In the circumstances, therefore, it was necessary to maintain the supply of rifles with Standard Small Arms bodies, and, accordingly, a contract was placed for an additional 20,000 sets.[5]

By the end of January, 1918, considerations had arisen to cause a modification of the October requirement, and the War Office notified the Ministry that 75,000 rifles per month should be sufficient to meet liabilities. "I am to say that, in putting forward this proposal, the Council desire to assist in conserving and employing the resources of this country in labour and material to the utmost, and it is thought that the reduction suggested will aid the manufacture of the various types of machine guns, and eventually result in an increased output."[6]

A scheme was, therefore, prepared in which the financial as well as the manufacturing point of view was considered. The most expensive rifles to produce were those made under the peddled scheme, and it was therefore proposed to bring that scheme to an end. The assembly of rifles made from Standard Small Arms bodies was to be reduced to 2,000 a week with a view to completing by the end of the year all rifles which would have to be produced in accordance with the terms of existing contracts with the Standard Small Arms Company. The contract would then be terminated. The company was accordingly instructed on 7 February to stop production upon the completion of the 218,000+20,000=238,000 sets already on order.[7]

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[1] D.D.G.E./E.M.3/672. D.M.R.S. 135A/1; 77/15/5378.
[2] D.D.G.E./E.M.3/707. [3] D.D.G.E./E.M.3/762.
[4] D.D.G.E./E.M.3/814. The proposal was:—

January	9,000 p.w.	May	7,000 p.w.
February	8,500 p.w.	June	6,500 p.w.
March	8,000 p.w.	July	6,000 p.w.
April	7,500 p.w.		

[5] *Order and Supply List.* E. No. 126 (24.4.18).
[6] Letter of 31 January, 1918; copy filed in D.D.G.E./E.M.3/850.
[7] D.D.G.E./E.M.3/849.

As rifles in excess of 10,000 a week made by the Royal Small Arms Factory were assembled largely from parts taken from the component pool and were expensive to manufacture, the output at the factory was to be reduced to 10,000 rifles a week.

The programme of reduction as prepared by the Birmingham Small Arms Company was to stand.

The production of the London Small Arms Company was third in order of expense, and it was, therefore, decided to order the company to cease working night shift, leaving a capacity of about 1,250 rifles a week.

The operation of this scheme seemed likely to result in a surplus of 50,000 rifles during the period necessary for reduction, and an output of rather more than 75,000 rifles a month during the current year, with a potential output of 70,000 rifles a month after the end of 1918.[1] In view of the practical impossibility of subsequently increasing output after the reduction had been established, the excess indicated was considered as likely to be a not undesirable addition to reserve stocks. Any further reduction, if required, would depend on the programmes of Enfield and the Birmingham Small Arms Company in connection with machine gun output, and the concurrence of the War Office in the scheme was sought.[2]

Subsequent increases, however, in the demand for machine guns altered very considerably the whole position regarding rifle and machine gun supply, and towards the end of February a further revision of the allocation of rifle output among the factories was necessary.

The new situation appeared to require the output of a maximum number of machine gun parts, and as Colonel Halse was convinced that much more could be done in that connection by the Royal Small Arms Factory than by the use of small contractors who had been producing components for peddled rifles, it was arranged that the peddled scheme, in spite of its expense, should be continued, that both its capacity and that of the London Small Arms Company should be retained at the maximum output, and that the relief which would thus be given should be entirely taken up at the Royal Small Arms Factory with a view to the development of machine gun part manufacture. The new programme which was adopted was, therefore, 7,000 rifles from the Royal Small Arms Factory per week, 4,000 peddled rifles with Standard Small Arms bodies, 2,000 from the London Small Arms Company, and 6,000 from the Birmingham Small Arms Company.

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[1] *Output in February*, 1918.

	p.w.
Royal Small Arms Factory	11,400
Standard Small Arms Bodies	3,000
Birmingham Small Arms Co.	9,000
London Small Arms Co.	2,000
	25,400

Output as reduced.

Royal Small Arms Factory	10,000
Birmingham Small Arms Co.	6,000
London Small Arms Co.	1,250
	17,250

2,000 with Standard Small Arms bodies until the end of the year.

[2] D.D.G.E./E.M.3/850; D.M.R.S. 135A/1; 77/15/5378.

The supply of major components for peddled rifles seemed reasonably secure, and the Standard Small Arms Company was instructed that the letter terminating their contract was withdrawn and that they were to proceed with the manufacture of 4,000 sets of components weekly until further notice.[1]

(*d*) EFFECTS OF THE GERMAN ADVANCE.

The reduction of the Enfield output was begun, and the delivery of factory-made rifles had reached 8,300 a week,[2] when, owing to the losses in the field, it became necessary to reconsider the position. By 12 April, according to the latest information available, the stock of rifles at the base in France had fallen from 88,000 on 21 March to 76,000 on 31 March, and stores in Great Britain had fallen from 360,000 on 21 March to 120,000 on 10 April. Over a considerable period preceding the offensive, of the output of 25,000 a week, 10,000 went to replace wastage and 15,000 had been put into stock. It was, therefore, necessary to rebuild the store, and to this end the War Office early in April increased the rifle requirement to 100,000 a month. This demand affected the whole of the rifle and machine gun situation, and on 17 April the Ministry of Munitions put forward a counter proposal for an output of approximately 90,000 a month,[3] pointing out that any increase beyond this number would involve a disproportionate loss on the output of machine guns. The scheme was approved,[4] and while the Royal Small Arms Factory was working up to the maximum required, the Birmingham Small Arms Company reduced at a slower rate so as to keep up the total deliveries. By the end of July the weekly output had again reached approximately 24,000 rifles.[5]

(*e*) PROJECTS FOR NATIONAL RIFLE FACTORIES.

In the early part of 1918 the desirability of issuing an automatic rifle which should be capable of use with a bayonet was the subject of serious consideration by the War Office and by the Ministry of Munitions. There was some difference of opinion on the necessity for such a weapon, and of the various types submitted, while none was ideal, the most promising appeared to be the Farquhar Hill rifle. It had previously been tried and rejected, but in January, 1917, the War Office had ordered 20, and in May, 1918, a further 20, increased during the same month to a definite requisition for 100,000. It was estimated that it would take from 15 to 18 months after the completion of the drawings to produce 1,000, and the model was yet to be accepted, but preparations were begun at once.[6]

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[1] D.D.G.E./E.M.3/849.

[2] (Printed) *Weekly Report*, No. 137, Table VIII (13.4.18).

[3]

Royal Small Arms Factory and peddled rifles	15,000 p.w.
Birmingham Small Arms Co.	6,000 ,,
London Small Arms Co.	2,000 ,,

[4] D.M.R.S. 135 A/1.

[5] Enfield 9,900 ; Peddled rifles, 4,100 ; Trade, 10,000.

[6] D.D.G.E./E.M.3/848. D.D.G.E./E.M.9/75.

The factory of the Standard Small Arms Company was taken over for the manufacture of the more important components, and with Mr. Peterson as superintendent, became in June, 1918, the National Rifle Factory No. 1. For the production of stocks and barrels a new factory belonging to Messrs. Greener was also taken over as the National Rifle Factory No. 2. The cost of acquiring the land and buildings of these two factories was £131,732. For minor components contracts were placed with various firms and a drawing office was set up in London. It was also proposed to take over the Training School at Birmingham for inspection, proof and assembling, but this plan did not materialise. Progress, however, was extremely slow.[1]

(*f*) Arrangements for decreasing Supply.

In July, 1918, the War Office again reconsidered their requirement for R.S.M.L.E. rifles, and fixed their demand at 90,000 a month exclusive of repaired rifles during the current year, with 75,000 per month inclusive of repairs for the year 1919.[2] The Ministry of Munitions pointed out that the conversion of the Standard Small Arms Factory would result in a shortage of from 20,000 to 40,000 rifles by the end of the year, but, as it seemed probable that this number would be made good later, the War Office did not raise any objection. Owing to the irregularity in the supply of repairable rifles, the Ministry of Munitions also asked for the 1919 requirement of new rifles and eventually the number was fixed at 60,000 per month.[3] On the existing position a considerable reduction in the output of new rifles during 1919 seemed possible, but the general programme was unsettled owing to the uncertainty of the future of certain machine guns and of the Farquhar Hill rifle.[4] Meanwhile, the output at Enfield was reduced so as to spread deliveries over a longer period. At the end of September, output was further reduced by 1,000 rifles a week, and arrangements were made both with the Superintendent of Enfield and with the Chief Ordnance Officer to reduce manufacture to the fullest possible extent by using components which were in existence in factory stock, peddled stock and on repair ledger charge, and by using surplus stocks held at Weedon as spares.[5]

The general programme was settled early in October. The Farquhar Hill rifle was abandoned since it was impossible to obtain rifles in time to train the troops for the spring campaign. Both National Rifle Factories were to be shut down as soon as possible, and a fresh cut was arranged for Enfield and for the trade.[6] By the end of the month the output from the Royal Small Arms Factory was about 7,500 rifles per week,[7] and on 8 November, an immediate reduction to 80,000 rifles per month inclusive of repairs was suggested.

[1] D.D.G.E./E.M.99; see also Vol. VIII, Part II, pp. 230–231, for a detailed account of these factories.
[2] D.M.R.S. 135 A/1.
[3] D.M.R.S. 135 A/1.
[4] (Printed) *Weekly Report*, No. 160, VI, B (21.9.18).
[5] D.D.G.E./E.M.3/1155. D.D.G.E./E.M.3/1154.
[6] (Printed) *Weekly Report*, No. 165, VI, B, (26.10.18). D.D.G.E./E.M.9/53.
[7] D.D.G.E./E.M.4/554.

(g) POST-ARMISTICE MEASURES.

With the signing of the Armistice, output was decreased very rapidly, and the figures for November and the first two weeks of December showed a reduction of 50 per cent. on the October numbers.[1]

The most considerable contracts were running contracts, and on these notices of termination for various periods were given. For fixed quantities each contractor was asked to cease production as soon as possible and to consult the Controller as to details.[2] No more material was to be put into work, and, generally speaking, satisfactory arrangements were made with the various firms.[3]

Of the rifle-making factories, the contracts with the Birmingham Small Arms Company were terminated in February, 1919,[4] but the settlement with the London Small Arms Company took some while, owing to the fact that they had on hand a somewhat excessive stock of components and material.[5]

At the Royal Small Arms Factory, staff was cut down at once. It was arranged that practically all the women should leave by 7 January, and that the men should be at the peace-strength of 1,800 by 31 March, 1919.[6]

Eventually, it was decided to cease the manufacture of new rifles, and to carry out repair work only, but enough material for the assembling of 100,000 rifles was to be retained, so as to allow time in case of an emergency for the factory to work up to 11,000 rifles per week.[7]

It was decided to retain all R.S.M.L.E. rifles, and any serviceable C.L.L.E. rifles, but to dispose of all others.

The dispersion of the highly skilled workmen, and the lack of practice to be provided for those retained was viewed with alarm, but taking into consideration the large surplus, the course adopted appeared inevitable.

II.—The Supply of Accessories.

Accessories for rifles were made both at Enfield and by the trade. The supply of most accessories increased with the development of rifle output. The demand for cavalry swords which were made at Enfield as well as by the trade fell off during the middle of 1916.[8] Bayonets and scabbards were also made at Enfield at the beginning of the war, but with the development of the peddled scheme[9] the bayonet shop was converted into a rifle-component shop, and the manufacture of bayonets entrusted entirely to the trade, i.e., to Messrs. Sanderson Bros. and Newbould, the Wilkinson Sword Company, Messrs. Mole, Messrs. Chapman and to Messrs. Vickers. The supply presented few difficulties. " The expansion of a well-organised running bayonet plant was shown by the Wilkinson Sword Company to be a simpler proposition than a similar

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[1] (Printed) *Weekly Report*, No. 171, VII, (7.12.18). [2] *Ibid.*
[3] (Printed) *Weekly Report*, No. 173, V, (28.12.18).
[4] D.D.G.E./E.M.4/631. [5] D.D.G.E./E.M.3/1327.
[6] (Printed) *Weekly Report*, No. 172, V, (14.12.18).
[7] HIST. REC./R/1402/1. [8] HIST. REC./R/1122.1/3. [9] See above, p. 18.

expansion in respect of rifles; on the other hand, Sanderson Bros. & Newbould failed badly in solving the same problem. Vickers took a long time to reach production, but the American firms were in front of their corresponding rifle output."[1]

Subsequent increases were all obtained by further extensions of the Wilkinson Sword Company's plant, the most dependable of the contractors.

Other accessories were made entirely by the trade, and except for watchfulness in the use of urgently required metals and so forth, it was possible except in the case of some of the tools, e.g., armourers' plates, if sufficient notice were given, to arrange for the production of almost any quantity. The real difficulty lay in finding out what numbers were required,[2] but even in the spring of 1918 the unexpected demand was met easily, and throughout the war much of the work consisted in keeping in close touch with the manufacturers, helping them out of difficulties, and spurring them on to increased efforts.[3]

III.—Repairing and Reconditioning of Rifles.

Salved rifles, the number of which varied very considerably with the season of the year and the nature of operations in the field, were all delivered to the Chief Inspector of Small Arms at Enfield, by whom they were issued for repairs and the stocks carefully watched so that output could be regulated as appeared desirable.[4] When the stock became excessive, the supply branch was notified and repair contracts were placed until the surplus was disposed of.

The bulk of the repair work for the first eighteen months of the war was done at the Royal Small Arms Factory, a certain amount was undertaken by the Chief Inspector of Small Arms, and contracts were also made with the trade.[5] Early in 1916, the proportion of salved rifles which could be dealt with by the trade was estimated at 20 per cent.

With the formation of the rifle component pool,[6] all parts in excess of those actually required for the output of complete rifles were pooled and those needed for repair work were drawn from this pool. Through the use of this stock, the Royal Small Arms Factory was able to meet satisfactorily demands which could not otherwise have been dealt with from Enfield.[7]

In the early part of 1918, through a fresh arrangement the responsibility for the charge and repair of salved rifles was transferred from the Inspection Department to the supply branch.[8]

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[1] Sec./R.S./135.B/1.

[2] HIST. REC./R/1400/21. D.D.G.E./E.M.3/848.

[3] HIST. REC./R/1400/3.

[4] D.D.G.E./E.M.3/559; D.D.G.E./E.M.3/848.

[5] C.M.61. On 1 February, 1916, the Chief Inspector of Small Arms estimated that he would be dealing with about 1 per cent. of the repairs, but on 1 February, 1918 Col. Halse reported that the Chief Inspector had hitherto repaired a large quantity himself. D.D.G.E./E.M.3/848.

[6] See above, p. 20.

[7] HIST. REC./R/1400/21.

[8] D.D.G.E./E.M.3/848.

IV.—Supplies to the Allies and India.

(a) Russia.[1]

The failure of the American contractors to manufacture rifles to contract times affected the Russian forces most seriously. On the contracts placed direct by the Russian Government, rifles which should have been delivered in March 1915, did not come in till 1916, and then at first only from the Winchester Company, and in July 1916 of 1,200,000 rifles which had been promised only 14,000 had been received.[2] The firms on their part complained of the unreasonable delay of the Russian inspectors in reporting on rifles submitted to them.[3]

Moreover, new troops were to be armed and heavy wastage made good, so in February, 1916, a new Russian requirement for 2,700,000 rifles was laid by General Hermonius before the Committee for the Purchase of Russian Supplies, and delivery was asked for by the middle of 1917 at latest. After a full discussion it was agreed that, as the rifle-making capacity in the United States was already taken up, the only way to obtain these quantities was by using any surplus that might be available on British contracts, and in view of the apparent surplus of American rifles it seemed likely that 500,000 would be available by the end of the year, and, if deliveries came up to estimate, an additional one and a half millions during the first half of 1917.[4] This scheme involved the addition of yet another pattern rifle to those already used by Russian troops, but though the objection to this was recognised it was felt that, as such large numbers were to be supplied, the provision of a new type was justifiable.

The Russian Government agreed to accept the British pattern, and on 21 March, 1916, the War Office intimated their willingness to make over to Russia, after British requirements had been satisfied, two million rifles from American contracts.[5] After some indecision as to whether it would not be preferable to arrange for the manufacture of the Russian pattern rifle, the War Office on 18 May, 1916, finally approved that the representative of the Russian Government should be informed of their decision. The number was increased to 2,500,000 rifles with an adequate supply of ammunition, but delivery was not expected to begin until April, 1917, although it was hoped that this date might be improved upon.[6]

The Russian Government, however, was most anxious to obtain rifles before the end of 1916, and at a conference held on 13 July General Belaiew, the Russian delegate, expressed the opinion that the Russian home supply would probably be sufficient to meet needs by January, 1917, and therefore declined the offer of American-made rifles on the ground of late delivery.[7]

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[1] For previous history see Chap. I.

[2] On 2 February, 1916, General Hermonius had been of the opinion that though early deliveries would in the main be slightly delayed, the contractors would be up to the scheduled dates of delivery within two or three months. See Hist. Rec./R/1420/18, Appendix C.

[3] N.Y. 19179.

[4] See Chap. II, IV.

[5] Hist. Rec./R/1420/20.

[6] Hist. Rec./R/1420/18, Appendix B.

[7] Hist. Rec./R/1420/18.

There was some opinion that a certain number of rifles could have been made available by the end of the year if the War Office would defer the arming of home defence forces with up-to-date weapons, but the very slow delivery of American rifles made any such course impossible.

During the negotiations for cancelling the American contracts, the Russian Defence Committee, through Colonel Blair, expressed a wish to vary General Belaiew's decision and, affirming their dislike of the American-made rifle, asked for 700,000 British-made rifles for delivery during the first part of 1917. The War Office emphasised the fact that only pattern 1914 rifles were available and that deliveries could not begin until June, 1917,[1] but no definite conclusion was reached.

The balance of rifles not wanted by Great Britain on the amended contracts[2] was again offered to Russia but as deliveries were not likely to begin till August, 1917, the offer was again declined.[3]

The collapse of Russia left a large number of rifles still undelivered. The bulk of those which were being paid for out of American credits were retained in the United States, but a certain number which had been taken from diverted ships were stored in England. Rifles paid for out of British credits were shipped to England and stored.

In the middle of 1918 a use was found for these rifles.[4] Thirty thousand rifles were urgently needed "for a special purpose." The Russian rifles were brought out of store, inspected, cleaned and reconditioned, while the American property was not allowed to leave the country.

The rifles were far from reliable when judged by the R.S.M.L.E. standard, but it was estimated that about 90 per cent. were serviceable. The demand was increased to 94,000, and in October the War Office asked that 150,000 should be overhauled. The requirement was fully met to time, and the special purpose was revealed as the arming of the expeditionary force for North Russia.

(b) ROUMANIA.

Towards the end of 1916, the Roumanian Government reported a serious shortage of rifles and asked for the supply of 1,000,000. It was not possible for this number to be spared from British sources of supply, but the diversion of at least 100,000 from either the American contracts or the Ross output or out of the emergency rifle store was thought to be feasible. In view, therefore, of the situation in Roumania and of the statement that there were 300,000 trained men without rifles, the War Committee on 16 November, 1916, decided that the next 100,000 rifles from America should be sent direct to Roumania. This decision created rather a difficult situation in regard to Russia whose urgent requisition for rifles before the end of the year had been refused; but a telegram explaining that the arming of British troops had been delayed in order to help Roumania was sent to allay any resentment on

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[1] Telegrams P. 588, L. 22049, P. 599, P. 598, L. 22660. P — Petrograd. L — London.

[2] See below, p. 47. [3] D.D.G.E./E.M.3/359. [4] D.M.R.S. 135R.

the part of the Russian Government.[1] In view, however, of the uncertainty caused by the Roumanian retreat at the end of the year the allocation was cancelled and no rifles were sent.

(c) India.

Troops sent from India were equipped by the Indian Ordnance Department though their maintenance devolved to a large extent on the War Office. Similarly demands for Mesopotamia were made in the first place on India, and those which could not be met were transferred to the War Office. In respect of rifles, the factory production in India was sufficient to meet wastage, but owing to the fact that 23 out of 35 territorial and four garrison battalions sent out had had to be re-armed from Indian store, the stock had become very low and was quite inadequate to re-arm regiments on service which were badly needing the short magazine Lee Enfield rifles. Accordingly the Indian Government put forward early in 1916 a strong case for the immediate shipment of 26,000 rifles.[2] To meet this and other demands the War Office had declined to reduce the total 1916 demand,[3] and supplies were promised when the American orders should materialise.[4] The delay, however, in the delivery of American rifles prevented the fulfilment of the promise, and it was not until March, 1917, that it was found possible to authorise the shipment of 100,000 rifles to India from the Remington (Eddystone) factory.[5]

[1] Telegram L. 25448. [2] Hist. Rec./R/1420/20. [3] See above, p. 23.
[4] 57/16/7177. [5] L. 30708.

CHAPTER IV.

SUPPLIES FROM ABROAD.

I.—United States of America.

(a) ORGANISATION.[1]

The appointment of Messrs. J. P. Morgan as commercial agents to the British Government had proved a most successful step from both a financial and a business point of view, but Mr. Lloyd George on his appointment as Minister of Munitions was convinced that there should be someone invested with full powers to represent the Munitions Department in the United States, and accordingly Mr. D. A. Thomas (later Lord Rhondda) was sent out. His general mission was to ascertain the possibilities of America for supply, and his special instructions in regard to rifle production were " to take any steps to increase the supply at the earliest possible moment, and to find out whether it is possible to form a syndicate to manufacture parts of rifles in different works, and set up separate establishments for assembling."[2]

Enlisting the services of various independent representatives of the Government, he formed an Advisory Committee, and later the British Munitions Board, under the Chairmanship of General Pease, to deal with such matters as the examination of facilities for manufacture and the speeding up of deliveries.

At the end of 1915 Mr. Thomas returned to England and was succeeded by Mr. (later Sir Ernest) Moir, who re-organised the Board, allocating the responsibility for various classes of munitions to individuals, machine guns and rifles being placed under a single officer, aided by a rifle expert from Enfield.

Later in the year 1916 the Inspection Department, which had been quasi-independent, was re-organised by General Minchin and was known as the " Quality " as opposed to the " Quantity " Inspectorate of the Progress Department.

This arrangement continued in force till the entry of the United States into hostilities, and as the sale of the rifle plants to the United States Government was, with the exception of financial adjustments, effected within a few weeks of that event, the subsequent re-organisations of the British Munitions Department in the United States have no immediate bearing on the history of rifle supply.[3]

(b) STEPS TO SECURE SUPPLY, 1915.

Earlier in the year 1915 the War Office, though emphasising the importance of the investigation of every possible source of supply,[4] had considered that contracts already placed would be sufficient to

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[1] For arrangements made prior to June, 1915, see Chap. I.
[2] HIST. REC./R/1141/5.
[3] For further details see Vol. II, Part III. [4] L. 2603.

fulfil requirements, but in June, 1915, the Minister of Munitions, while anticipating that existing contracts would meet 1917 demands was, in face of the very large estimate of wastage given by the War Office,[1] determined to secure at least one million additional rifles for delivery before 31 December, 1916,[2] and prompt supplies during the early part of the year were stated to be of vital importance.[3] Early in August, 1915, Mr. Geddes wrote: "Our position as regards British rifles is far from satisfactory, and I feel very strongly that we should leave no stone unturned in our endeavours to obtain rifles in America for delivery up to the end of the next year."[4]

It was felt that, in addition to the Winchester Ilion and Eddystone factories, there must be in the country a large potential capacity for rifle manufacture, and instructions were given that every possible source of supply which gave promise of early delivery was to be thoroughly explored. A number of firms of varied standing, with and without experience in rifle or gun manufacture, expressed readiness to produce service rifles and promised early delivery,[5] but investigation of manufacturing capacity, financial position and technical qualifications led to the conclusion that the promises were not likely to bear fruit.[6]

The Ministry of Munitions, however, convinced of the possibilities of the newly adopted peddled scheme,[7] expressed a belief that if smaller firms under the direction of a thoroughly reliable organisation would concentrate on the manufacture of one or more parts, something substantial could be achieved with even better chance of early success than in England.[8] Reports were received from several new companies, such as the Empire Rifle Company, formed to organise rifle production by means of the co-operation of a number of small firms, but after the investigation of some twenty firms, as a result of which it again appeared that financial standing was often unsatisfactory and technical experience and organising ability lacking, General Pease reported on 28 August, 1915,[9] that no further supplies for delivery in 1916 were obtainable and that, as a large capacity was already available at the Ilion and Eddystone factories for 1917 production, it did not appear wise to embark on small contracts which would extend probably through that year.[10]

Meanwhile negotiations had been proceeding with the Remington Arms Company of Eddystone and as a result a contract was placed with them on 2 August for 500,000 rifles complete with sword bayonets and scabbards at $30 each to be delivered at the rate of 200,000 by 30 June, 1916, 200,000 by 31 December, 1916, and the remainder by 12 April, 1917, and an advance payment of 25 per cent. was agreed upon repayable in respect of as many rifles as remained undelivered by 12 April, 1917.[11]

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[1] See above, p. 17.
[2] L. 6044. L. 6163.
[3] L. 6357.
[4] 5 August, 1915. HIST. REC./R/1141/47.
[5] N.Y. 3794, 3859, N.Y. 4971, 5003.
[6] N.Y. 3764.
[7] See above, p. 18.
[8] L. 6044 and 6351.
[9] (Printed) *Weekly Report*, No. 7, II (11.9.15).
[10] N.Y. 7193, 7327.
[11] 94/R/207.

The Remington (Ilion) Company had given the War Office an option on their capacity,[1] and as they stated that they already had a capacity in excess of their requirements, it was decided, on the recommendation of General Pease,[2] to drop the peddling out scheme and to rely solely on one of the existing contractors for the remaining half million rifles required. A contract was therefore placed on 27 September, 1915, with the Remington Company of Ilion for 600,000 rifles with sword bayonets and scabbards complete, delivery to be completed during 1916. The price was to be \$30 less a deduction of 2 per cent. on the entire purchase price, and an advance payment of \$1,500,000, viz., the equivalent of \$2·50 on each rifle, to be expended on plant, etc., for extensions, was made.[3]

Time was the essence of the agreement and the buyer might refuse to accept and pay for any rifles which were not delivered by 31 December, 1916, provided that notice was given on or before 30 September, 1916. The advance was repayable in respect of any rifles undelivered at the end of the year. The number of rifles ordered in the United States was thus 3,400,000. Mr. Thomas, in his report, affirmed that "the development of facilities for the manufacture of rifles is on the whole the hardest problem with which I have to deal . . . There is no department of munitions production in which experience is so necessary, or equipment so difficult to obtain . . . no business so attractive to the irresponsible worker . . . The main difficulty of the assembling proposition is that of securing interchangeability of parts and this proved to be the rock on which practically every proposal of this nature split. It is fortunate, I think, that we have been enabled to meet your requirements without recourse to an organisation along these lines" (i.e. the formation of a syndicate).

There was considerable competition for the American market and, as in addition to France, Belgium and Russia, it was reported that Greece, Italy, Holland, Portugal and China were negotiating for the purchase of rifles, it was important in the interest of the British programme to make certain of 1917 supplies. Eventually firm options[4] were obtained from the three contractors on their 1917 capacity and the American supply appeared to be secure.

A progress report received at the end of August, 1915, showed a most encouraging prospect.[5] The Winchester Company expected to start deliveries on their first contract early in September, and to turn out 1,000 rifles per day by the end of the month, though in the opinion of General Pease, the latter figure was doubtful. On the second contract they expected output would begin early in October, attaining to 2,000 rifles per day by 1 January, 1916, i.e. some months ahead. The Remington Company of Ilion hoped to produce about 1,000 rifles a day in December, 1915. These estimates were so optimistic that they were never regarded as likely of fulfilment, and in the case of the Remington Company of Eddystone, no forecast could be given as their plant was not in working order.

[1] 94/R/6.
[2] (Printed) *Weekly Report*, No. 7, II, (11.9.15).
[3] 94/R/207.
[4] See 94/R/207.
[5] N.Y. 7185

Various troubles, however, among which were strikes, hindered output though the managements hoped that the delay would not be very serious. Nevertheless, an estimate received on 30 October was disappointing.[1] At the express instance of Lord Kitchener,[2] the firms were asked to state the deliveries they expected to make during November, December and January, and whether they could pledge their reputation that such deliveries would certainly be made, as the matter was of vital importance.

The Remington (Ilion) Company promised only 100/200 rifles during the month of November, 1,000 during December and 1,000 a day in January. The Winchester Company could not undertake any deliveries till January, when they expected to produce 500 per day, and the Remington (Eddystone) Company, while not in a position to give definite figures, hoped to begin shipments in January. Up to January, 1916, therefore, deliveries were likely to be 112,000 below forecast.[3] However, early in December Deputy Director-General (E) reported that the American prospect, though supplies were late, was cheerful,[4] and it was estimated that 2,667,800 rifles would be furnished by the end of 1916.

(c) FAILURE TO DELIVER TO TIME, 1916.

Early in January, 1916, the War Office, in comparing prospective deliveries with the requirement for the year, came to the conclusion that rifles had been over-ordered by them in America to the extent of 500,000,[5] and the Ministry of Munitions was asked whether arrangements could not be made to cancel the last half million of the order for one and a half millions placed with the Remington Arms Company, or to divert this number to the requirements of the Allies. In that case the Ministry also had over-ordered to the extent of the recently made contracts and over 2,000,000 rifles seemed likely to be available for the Allies.

On 14 January, however, a report from Major Smyth Piggott, the officer in charge of inspection of American small arms, showed that only six rifles had been completed by the Winchester Company, 14 submitted for inspection by the Remington Company of Ilion and that, although the Remington Company of Eddystone were making steady progress, deliveries would be considerably delayed.[6] In his estimate of 6 February, he suggested a total of 1,000 rifles as a probable figure for the month, increasing to 6,000 in March with a total of 1,529,500 by December, 1916; but Mr. E. W. Moir's report of 11 April gave an estimated total for the year of only 969,507 rifles beginning with a delivery of 1,107 in March.[7] A cable of 3 July[8] stated that the manufacture of rifles would be 30 per cent. below the total estimate up to the end of that month, that deliveries would be behind in August and September, but would ultimately reach the total by the end of the year.

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1 N.Y. 9598.
2 L. 10192.
3 (Printed) *Weekly Report*, No. 14, II (30.10.15).
4 (Printed) *Weekly Report*, No. 20, II (11.12.15).
5 HIST. REC./R/1420/1.
6 C.R. 4427.
7 N.Y. 162 43.
8 N.Y. 1325 R.

The actual wastage of rifles, however, proved to be so much less than the War Office calculations that Deputy Director-General (E) expressed the opinion that the actual requirements for American rifles during 1916 would not exceed 900,000, and would, therefore, be met.[1] Nevertheless by 14 August, 1916, only 95,542 rifles had been delivered out of 1,433,200.[2] As an average of a month elapsed before shipments were received, and as some few were also lost at sea, it thus became a question of cancellation of contracts, as a result not of over-ordering, but of failure to deliver to time.

(d) CAUSES OF FAILURE.

At the beginning of the war, both the American contractors and the British Government utterly failed to appreciate the effect of the pressure which would be put on American labour and material as a result of the enormous number and urgency of orders for all kinds of munitions, with the result that firms, owing to late delivery of machinery, shortage of machine tools, want of skilled labour, and a number of labour disputes, were unable to keep anything like contract dates. There was, in addition, the competition with other belligerent and neutral countries for American supplies.

Rifle supply, however, suffered from many special disabilities. In the first place, the rates of delivery promised in the early contracts were so far in excess of the then production in England that, as General Minchin observed " it is hard to understand how any one in their senses could have expected them to be realised. The Government, in their desire to obtain rifles, shut their eyes to possibilities and pressed the firms to promise what was wanted, knowing there was no other source of supply."[3] Managements and staffs alike were ignorant of what a military rifle required, and entirely under-estimated the time needed to produce such an exact piece of mechanism. In fact, the Remington Company of Ilion had confidently expressed their expectation of earning the bonus of $1 offered on every rifle delivered before 31 July, 1915.[4] In November, 1916, Colonel Byrne after a thorough investigation into the whole question of rifle supply, wrote :—

> " What in my opinion has really delayed output apart from normal reasons due to difficulties and delay in obtaining plant has been an almost total absence of experience in the manufacture of a military rifle. The Winchester and Ilion Companies had developed a considerable trade in weapons of a sporting type, and in their opinion their products were of a standard far superior to that required for a military rifle. When they realised that the requirements of a military rifle were so far in excess of what they counted on, they sought about for excuses, and the first they came upon was severity of inspection."[5]

The companies complained bitterly of the rigidity of the British inspection, especially upon points which they regarded as unessential. " When orders were placed it was distinctly understood that the

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[1] HIST. REC./R/1420/19.
[2] HIST. REC./R/1420/17.
[3] HIST. REC./R/1420/15.
[4] 94/B/594.
[5] D.G.A.T./3.

Government was in sore need of rifles and would be quite willing to accept a serviceable rifle, and it was never understood or contemplated that the inspection would be so severely critical or minute as has obtained since the outset."[1] It was, however, essential that the troops should have full confidence in the rifles issued to them, and the rejection of the Ross rifle by troops in the field and the large percentage of American rifles made for Russia which were found to be unserviceable upon examination, proved the necessity for a high standard. In fact, Colonel Byrne, in the letter quoted above, stated that " the inspection has been, if anything, on the lenient side."

A main cause of delay, however, was the unstandardised pattern of rifle. There was a tremendous amount of experimental work to be done, which took far longer than was expected, and even when the model rifle was accepted defects due to faulty design appeared, and the companies, during the negotiations of the autumn of 1916, insisted that the rifle was still in the experimental stage and that upwards of 20 changes had been made.[2] Sir Ernest Moir wrote concerning the Winchester Company—" They have undoubtedly a *force majeure* clause, and can make a case for delay due to changes in design, whether of an important or minor character."[3] The British inspectors maintained that alterations had been made often at the express wish of the contractor or to facilitate manufacture and nearly always had been arranged so as to interfere but very little with output; but the fact remains that the unstandardised pattern was the source of much trouble. The frequent changes necessitated adjustments of machinery, and manufacturing delays further occurred through the production of badly fitting parts and the failure of parts. A large number of unsuitable components were produced which blocked assembly and at one time over 50 per cent. of the machinery in all factories was idle on account of the difficulties in assembling.

In addition to a faulty treatment in hardening, there were two main causes to bring about this state of affairs, want of gauges and lack of suitable labour. One of the original reasons for the choice of a new pattern rifle for manufacture in America was that gauges for the R.S.M.L.E. rifle could not be supplied from England in sufficient quantities for the contractors' needs and it was necessary for the firms to manufacture their own gauges.[4]

In regard to labour, there was a great shortage of experts. It was estimated that there were not enough skilled workmen in the country to staff even one of the factories as enlarged, and the dearth of barrel straighteners and men for stocking proved a very serious hindrance to output.

The supervisory staff also was far from satisfactory. Of the Winchester Company, Colonel Byrne reported that the shop inspection was organised on sound lines and the system for checking wear and gauges was good, but that the examiners allowed components to slip through which were not always true to gauge; of the Ilion works

[1] N.Y. 29013.
[2] N.Y. 29014.
[3] Hist. Rec./R/1420/17.
[4] Vol. VIII, Part III, pp. 12-17.

that there was a striking absence of supervisory staff of the higher grades, that there was a lack of intelligence on the part of the examiners and a further lack of intelligent supervision. "The supervision is there but it is as faulty as the work it supervises."[1]

In the case of the Winchester Company, the management was reported to be disappointing and lacking in vigour[2] and to have adopted the view that their domestic trade, as being more remunerative, should at least be on an equal footing with war contracts. In the opinion of Sir Ernest Moir, this commercial attitude was largely due to the system of the British Government in paying large sums on account: the profits were absorbed and sunk into the business before the rifles were made and there was accordingly no incentive to deliver large numbers.[3]

A disadvantage under which American contractors suffered was in not having until a comparatively late date an expert to carry out the tests to which rifles were subjected at Hythe and by the troops,[4] and another set-back occurred in the discovery that rifles which functioned properly with American cartridges failed to do so with British ammunition.

Colonel Halse, however, considered that much of the delay was preventible. He was of the opinion that the Americans had been far too slow in evolving a correct pattern after the model had been accepted, that they had failed to train men until rejections actually occurred, and that they had given rise to many of their own manufacturing difficulties by taking the whole toleration allowed on each individual component.[5]

The pattern, indeed, was never wholly satisfactory. There was always trouble with the extraction and feed-up of the cartridge, so that in January, 1917, it was finally recommended that the American rifle should not be used in the more important theatres of war, as the standard of manufacture and interchangeability was not likely to reach that attained in England.[6]

(*e*) THE AMENDMENT OF CONTRACTS.

The effect of the American failure was serious. There was no doubt that had all the rifles been delivered at dates approximating those promised the position both of the British and the Allies in the field would have been very different.[7]

In the course of 1916 it became abundantly clear that the War Office requirements for 1917 would be met from British sources.[8] An offer of the surplus American supplies had been made to Russia and refused,[9] and the question of cancellation of the contracts began to be seriously considered.

There were several problems to be faced, (*a*) the effect on supplies, (*b*) the political factor, (*c*) the financial aspect, (*d*) the cancellation date.

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[1] D.G.A.T./3. [3] HIST. REC./R/1420/17.
[2] N.Y. 19213. [4] HIST. REC./R/1420/15. [5] HIST. REC./R/1420/15.
[6] Letter to War Office 19th January, 1917. Volunteer units were armed with pattern 1914 rifles in August, 1917.
[7] HIST. REC./R/1420/17. [8] See above, p. 27. [9] See above, p. 39.

(*a*) As a result of their failure to produce enough rifles to pay for capital outlay, all three companies were in financial straits. On 11 August, 1916, Sir Ernest Moir reported—" All the Companies . . . . . seemed to think that if they were not able to live up to my estimate, they would be all ruined. The Winchester Co. are in a poor financial condition. The Remington (Bridgeport) Co. we now hear are in a bad way financially. This Company is closely allied to the Remington Co. of Ilion. The Remington Co. of Eddystone will, in my opinion, sooner or later be in financial difficulties."[1] If, therefore, the contracts were cancelled to their full amount, it was possible that all three firms would go bankrupt and that, as a consequence, not only would the rifles which were needed during 1917 be lost, but the urgent Russian supplies ordered from the same firms would also be prejudiced. In September, General Minchin wrote that the Anglo-Russian contracts were all in a most unsatisfactory state and that the British Government was responsible as it made the contracts.[2]

Even should the firms not go bankrupt, it was considered not unlikely that they might slacken or even purposely retard output.

Moreover, if the rifle manufacturers were allowed to go bankrupt it was most probable, especially in view of the fact that the financiers backing the firms were prominent men, that supplies of other munitions would be adversely affected and that firms would press for hard bargains and severe conditions which would in the long run involve the Government in heavy expenditure.[3]

(*b*) Sir Ernest Moir and General Minchin both pleaded for leniency. " We ought to treat the American rifle manufacturers liberally in view of their being in a foreign country, and we do not wish to raise opposition which is unjustified. . . . Undoubtedly, we do not wish to produce the impression of either being harsh or grasping."[4] " I am faced with the situation here. The Germans and Irish are bitterly hostile. A large section of the community are hit and annoyed by the working of the blockade. Any serious failure among the big munitions plant will cause great uneasiness. . . . I strongly advise going slow with cancellation . . . as all the firms have played up and done their best, except perhaps Winchester, and they are trying hard. I am very zealous for the reputation of our Government for fair and honest dealing out here."[5]

In connection with the financial condition of the Remington Company Messrs. Morgan wrote that it would be " little short of a calamity if (they) are permitted to fail: the effect upon munitions contracts and financial operations of the British Government would be most serious."[6]

At this time, moreover, the British Government was preparing to negotiate a loan in the United States, and although not realised at the time, it soon became apparent that if the rifle contracts were cancelled the chances of its success would be very remote.

[1] Hist. Rec./R/1420/17. [2] See above, p. 13. [3] N.Y. 25663.
[4] Notes on rifle contracts in U.S.A. 11 August, 1916. (Hist. Rec./R/1420/17.)
[5] Gen. Minchin to the Minister (16.9.16). Copy filed in Hist. Rec./R/1420/15.
[6] Hist. Rec./R/1420/20.

(*c*) So far as concerned the financial position of the British Government, and as, in respect of undelivered rifles, deposits made in advance were to be refunded on cancellation of the contracts, there would be no loss except possibly on the Remington Company's first contract, under the terms of which the advance of $11,250,000 had been definitely expended on plant which would only become the property of the British Government if not less than 1,000,000 rifles had been delivered at the termination of the agreement.[1] On the estimate of Deputy Director-General (E) not more than 638,500 rifles could be delivered before 31 March, 1917, but the plant could be obtained by placing an additional order for some 360,000 rifles.

(*d*) There were some difficulties in fixing the date of cancellation owing to the fact that, on the first contracts, deliveries were to be reckoned from the date of acceptance of the modified rifle model.[2]

The date of acceptance had been fixed at 24 or 25 March, 1915, but as various alterations in design had been made subsequently, the contractors claimed additional consideration.[3]

A further complication arose in that, prior to the discussion on cancellation, all three companies had applied for extension of time, which in the case of the Winchester Company had been granted to a date beyond that suggested for cancellation.[4]

In a statement of 20 July, 1916, Deputy Director-General (E) pressed for a decision on the disposal of the 2,500,000 rifles,[5] and proposed to take deliveries up to the 31 December on the first Winchester and Remington (Ilion) Company's contracts,[6] and to cancel the others.[7] He estimated that the total number of rifles then delivered would be 883,500, *i.e.*, 121,000 from Winchester, 124,000 from Remington (Ilion) and 638,500 from Remington (Eddystone).

On 7 August, 1916, the War Office agreed to the immediate cancellation of 1,900,000 rifles and intimated the possibility of a further reduction.[8] However, consequent on the increased demand for rifles for the last part of 1916, it appeared that in addition to the 1916 deliveries some 800,000 American rifles would probably be needed in the early part of 1917 to make up the deficit on the 1916 supply,[9] and another proposal was submitted suggesting the cancellation of 1,600,000 rifles.

Sir Ernest Moir indeed advocated an extension of time of from three to six months on all contracts, but to this plan the objection was raised that the contractors might deliver a large number of unsatisfactory rifles, and then claim that the inspection was unfair,[10] and the War

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[1] 94/R/39.
[2] Contracts/B/7235.
[3] N.Y. 27424 in HIST. REC./R/1420/15.
[4] N.Y. 25663.
[5] HIST. REC./R/1420/18.
[6] *i.e.*, Contracts/B/7231, for 200,000 and Contracts/B/7235 for 200,000.
[7] *i.e.*, for 200,000, 200,000, 600,000, 1,500,000 and 500,000. See above, p. 26.
[8] 54/Gen. No./2356.
[9] See above, pp. 26, 27.
[10] HIST. REC./R/1420/17.

Office agreed to the cancellation of 1,800,000 rifles, increasing the suggested number by 200,000 in order that it might be reduced during negotiations. On 23 August, Messrs. Morgan were instructed to cancel 1,000,000 rifles under the Remington (Eddystone) contracts, 200,000 under the Winchester Company's contracts and 600,000 under agreements with the Remington Company of Ilion.[1] Messrs. Morgan protested strongly against the action of the Government and pleaded for a more equitable adjustment,[2] and General Minchin added the weight of his influence to the plea for generous treatment,[3] but on 21 September the notices were issued.

American contractors were, at the same time, protesting strongly against the rigidity of inspection, for the standards originally adopted had proved over-lenient and it had become essential to tighten up inspection generally, so that the rifles ultimately produced might be acceptable. The companies pointed out that they had accepted additional orders in 1915 and extended their plant only with extreme reluctance and because of their earnest desire to fill the pressing requirements of the Government, and complained that the inspection had of late become " so exacting and rigid as to render impossible production at a reasonable cost or on a large scale."[4] The general feeling throughout the United States was that the change in policy was due to the fact that the former need of rifles had largely disappeared owing to the new methods of warfare, and to the development of British industries by Mr. Lloyd George, in short,[5] that American rifle contractors, after working and developing to their utmost, had been summarily cast aside. The companies announced their intention of stopping manufacture until a reasonable solution should be arrived at, but finally agreed to go on for one week at a reduced output, pending negotiations.

Messrs. Morgan insisted most strongly on the disastrous effect that the financial crisis would have on the forthcoming loan. " The rifle situation has an important bearing upon immediate and ultimate financial plans . . . it is difficult to convey by cable the importance it has in the minds of prominent men."[6]

A conference was held in London, at which the Chancellor of the Exchequer and Mr. Davidson, of Messrs. Morgan, Grenfell & Co., were present, to discuss possible solutions. The Ministry hastened to assure Messrs. J. P. Morgan that rifles were needed, offered to cover the payment of the cost of manufacture for two weeks, and while not prepared to go into the business of rifle manufacture, expressed their readiness to fall in with any reasonable proposal.[7]

The companies had proposed to turn over the whole of the plant to the British Government who finally conceded this principle of settlement[8] and fresh agreements were drawn up with effect from 21 October, 1916, by which the notices of 21 September were withdrawn

[1] L. 22274.
[2] N.Y. 25663.
[3] Hist. Rec./R/1400/15.
[4] N.Y. 29014.
[5] N.Y. 29013, 29014, 29045.
[6] N.Y. 29013, 29045.
[7] N.Y. 24557.
[8] N.Y. 29014 and L. 24664.

and the former contracts modified and amended. In each case the number of rifles was reduced in the proportion 10 : 17 so that the quotas were

235,293 from the Winchester Company,
588,236 „ „ Remington (Ilion) Company,
1,176,471 „ „ „ (Eddystone) Company,

with spare parts up to, but not in excess of, 10 per cent. The final dates were extended to 15 August, 1917, in the case of the Winchester Company, and 31 December, 1917, in the case of the others. The Government reserved to itself the right to discontinue manufacture by giving 30 days' written notice.

In lieu of the prices and terms of payment specified in the original contracts, the Government agreed to make payment to the contractors in respect of certain items of capital outlay, and undertook to defray the entire cost of manufacture, and also waived all claims for the repayment of advances made under the original contracts. Upon the termination of the contracts as amended, the machinery was to become the sole property of the Government, but if any additional orders were given, or if rifles were required after the final date as amended, the manufacture was to be at such reasonable profit to the contractors as might be then agreed upon.[1]

In November, 1916, the War Office had intimated their willingness to reconsider their demands, and on 11 January, 1917, agreed to reduce their 1917 requirements of pattern 1914 rifles to 800,000.[2] Owing to faulty manufacture it had been found advisable to reduce the Remington (Ilion) order to 400,000 rifles,[3] and it was decided that the balance should not be made up. In February, the quotas of the other firms were reduced, that of the Winchester Company to 235,000 and of the Remington (Eddystone) Company to 500,000.[4] The War Office stated that a total of 1,060,000 without spares would meet requirements.

It was estimated that losses in transit would be met from a surplus in home supply, and unless Russia needed any further supplies, deliveries were to be stopped as soon as the number of rifles required was completed.

(*f*) DISPOSAL OF PLANT.

Early operations on the more complicated components began to stop early in 1917, and on 15 January Messrs. Morgan cabled that fully 50 per cent. of the machinery at the Winchester and Ilion plants was idle.[5] It was estimated that deliveries would be completed by the Winchester Company in June, and by the Remington Company of Ilion in October, and by the Remington Company of Eddystone in December, 1917, and the question of the disposal of the plant was under discussion. The Colonial and India Offices were approached with a view to the purchase of all or part by India or the Colonies,

[1] HIST. REC./R./1141/77.
[2] 54/Gen. No./2356; D.D.G.E./E.M.3/359.
[3] See D.G.A.T./3.
[4] 54/Gen. No./2356; D.D.G.E./E.M.3/359.
[5] N.Y. 35483.

and in the case of an embargo by the United States, the advisability of storage of the idle plant in Canada was under consideration. Another suggestion was the use of suitable parts for the equipment of a National Machine Gun Factory,[1] and by 4 April the disposal scheme had reached the point that the "E.W. Moir Organisation" had been asked to arrange for the collection of sufficient machinery for the manufacture of spares, and that while India had expressed willingness to take part of the plant to meet an unfilled requisition, replies from the Colonies had not been received, and that a letter opening the way for possible negotiations for sale to the United States Government had been prepared. In response to an enquiry from Messrs. Morgan, the Ministry had agreed to sell or lease complete plants to national organisations in the United States,[2] when the declaration of war by the United States against Germany altered the situation completely.

The United States Government put forward a requisition for 1,000,000 rifles. To safeguard the British supply, and to ensure a speedy output for American needs the Ministry suggested that the United States Government should adopt the pattern 1914 rifle and that the contractors should work the plants for both Governments, finishing the British orders as quickly as possible.[3] The United States Government, however, decided to adopt a modified Springfield rifle, and on 12 April Sir Hardman Lever was sent out with full power to negotiate on behalf of the British Government.[4] The Ministry expressed a preference to sell outright, and this was arranged on the basis of an understanding reached with Mr. F. A. Scott, the Chairman of the General Munitions Board.[5] The sum of $9,000,000 was to be paid to the British Government in respect of machinery equipment, tools, dies, jigs, fixtures, cutters and gauges which had been used or were in use at the time of transfer, and small tools which had not been used and were needed by the United States Government were to be purchased by them at cost price in the case of tools bought outside the plants, and at cost plus an overhead charge for tools made inside the plants. In regard to materials, raw and in process of manufacture, the United States Government agreed to take over such as were available for use at cost price plus 10 per cent. on raw material cost and in respect of finished and unfinished components to accept those which were serviceable. Unserviceable parts, tools, etc., were to be delivered to, or sold for, the account of the British Government, who were also to retain or remove uncrated machinery. The transfer of machinery and plant was to be as from a certain date and hour, and by a mutual understanding plants were to be used to finish the 1,250,000 rifle contract for the British Government, and to begin the 1,000,000 rifle contract for the United States Government simultaneously.

Except, therefore, for the final financial settlement, which was not completed until 1918, the history of the American rifle contracts ceases in April, 1917.

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[1] D.D.G.E./E.M.3/338.
[2] N.Y. 41081 and proposed reply in D.D.G.E./E.M.3/478.
[3] L. 34536.
[4] N.Y. 41655. L. 34658.
[5] D.M.R.S. 135 A.4.

II.—Canada.[1]

(a) THE FAILURE OF SUPPLY AND ITS CAUSES.

The Ministry of Munitions on its foundation was faced with a most unsatisfactory state of affairs in regard to the Ross rifle agreement. Promises of improved deliveries during June, 1915, were not carried out by 21 June; the 110 rifles which had been produced for inspection were all rejected; deliveries, therefore, were 12,500 in arrears and General Pease submitted that the agreement should be cancelled.

On 21st July General Pease reported that no deliveries had been or were likely to be made and again pressed for cancellation. A cable from Mr. D. A. Thomas on 14th August recommended the same course, as only a few hundred rifles had been produced for inspection and none had been passed up to that date. Nineteen finished rifles were accepted by 21st August and 150 by 31st August. During September about 50 rifles a day were assembled, but a report showed that there was no prospect that deliveries would be complete before March, 1917.

Sir Charles Ross ascribed the delay firstly, to modifications ordered by the Inspecting Officer in the rifle and accessories, secondly, to the difficulty of obtaining seasoned wood and skilled labour, especially barrel straighteners, thirdly, to unsynchronised plant and the late delivery of new plant ordered from the United States, and lastly, to the high standard of accuracy demanded by the Inspection Department, and pressed for further orders, pointing out the economic importance of using in the field a rifle of Canadian manufacture.

(b) REJECTION OF ROSS RIFLE AS A SERVICE WEAPON.

In June, 1915, Sir John French had, as a result of the increasing want of confidence in the rifle shown by the troops, re-armed the 1st Canadian Division with Lee-Enfield rifles,[2] but Mr. Lloyd George was of the opinion that the rifle, while not ideal, would, with adjustments, prove a serviceable weapon, and in view of the desirability of increasing the output of rifles under the British flag, the further use of the factory for rifle production was considered advisable.

Alternative proposals for nationalising the factory, or transferring the War Office order to the Canadian Government were in turn abandoned and the contract was continued without regard being had to it as a source of supply.

On account of rumoured dissatisfaction with the rifle, the Canadian Government, which in April, 1916, had contemplated placing additional orders, thought it well to have an exhaustive test made under active service conditions. The result was unfavourable. Sir D. Haig recommended that the 2nd and 3rd Canadian F. Divisions should be re-armed with Lee-Enfield rifles, and in July, 1916, the Army Council undertook the responsibility of supplying Canadian troops with rifles on their arrival in England.

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[1] For previous history see Chap. I; HIST. REC./H/1142/1, *passim.*
[2] 77/15/5307.

The Canadian Government thereupon began to consider the possibility of adapting the Ross rifle factory to the manufacture of a rifle which should be useful during the war and likely to be used by the Imperial Government after the war. The pattern 1914 rifle was suggested, but the Ministry of Munitions stated that the post-war standard design had not been decided upon, and declined to change the type of rifle under order for themselves on the ground that deliveries of the new pattern could not begin until all requirements would be met from home supplies, and that the Ross pattern was still useful for training purposes.

(c) THE FINAL CANCELLATION.

In February, 1917, the question of final cancellation was discussed. Up to 23 December, 1916, only about 43,000 rifles had been accepted, and as, in view of the unsatisfactory reports on the rifle as a service weapon, high priority in shipment appeared undesirable, the Army Council agreed to the proposed cancellation, which took effect on 24th March, 1917. The Canadian Government also cancelled an order for 100,000 rifles, and Sir Charles Ross closed the factory.

CHAPTER V.

REVIEW.

I.—Difficulties in Supply.

(*a*) Manufacturing Problems.

"Of all the weapons in use in modern warfare, there is scarcely any which requires a greater degree of accuracy or calls for more skill in manufacture than the rifle."[1] Moreover, as the number of men who could be put into the field was limited to a large extent by the number of rifles available, and as the serviceableness of each individual rifle was absolutely essential, the development and maintenance of the large output required proved a severe tax upon men, material and machinery.

The large number of components in each rifle, many of them very small, only served to intensify the difficulty of securing absolute accuracy when maker or workman was unfamiliar with the manufacture,[2] and while no insurmountable troubles occurred in the supply of material, the wood and steel of which the bulk of the components were made both presented special problems. Sixteen different classes of steel, each requiring a different heat treatment, were in use, and a knowledge of the structure and properties of steel was indispensable for a manufacturer. The London Small Arms Company in particular experienced difficulty both in getting steel to machine satisfactorily and with hard spots in barrel steel.[3]

The shortage of seasoned wood was a ceaseless anxiety to the Superintendent at Enfield, from whom all supplies to rifle and component makers were issued. In spite of experiments with beech, birch and mahogany, Queensland maple and many other woods, the only really satisfactory wood for use in rifle manufacture was proved to be walnut. Soon after the outbreak of war European sources of supply failed, and with the depletion of stores in Great Britain it became necessary to look to America. Upon this source reliance was placed for the whole of the supply, and herein lay the chief cause for anxiety. It was never possible to arrange for the shipment of sufficient quantities to create a good reserve store in England, and the supply of wooden components therefore depended on the unfailing regularity of transport. In June, 1917, only sufficient wood was in store for eight weeks' cutting; a week's cutting covered only a week's consumption, and the activity of the enemy submarines during this year was at its height.[4] The system of stacking roughly cut stocks until they were thoroughly

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[1] *Ministry of Munitions Journal*, No. 21, August, 1918.

[2] See above, pp. 7, 43.

[3] Contracts/R/2524; Contracts/R/2525; cf., (Printed) *Weekly Report*, No. 81, V, (24.2.17); 94/R/268; see above, p. 7.

[4] Hist. Rec./R/1122.1/3; D.D.G.E./E.M.3/803; D.D.G.E./E.M.3/970; D.D.G.E./E.M.4/126, 330; D.D.G.E./E.M.3/852.

seasoned and dried called for special storage facilities which were difficult to obtain at Enfield where most of the wood was kept, and there was a constant danger of fire, which was, however, greatest in the processes of manufacture.[1]

The late or non-delivery of machinery on order was a most serious problem. Replacements were constantly necessary owing to heavy wear and tear,[2] and even when the machinery was in place the preparation of fixings, gauges and tools took some months, but the partial delivery of machinery presented the worst difficulty. Rifle plant when complete is practically synchronised, and the absence of certain essential units restricted to a considerable extent the productivity of the whole plant.[3] The problem of extending capacity was thus far more difficult than the establishment of plant for making other munitions, which could be installed unit by unit.

Again, the necessity for absolute interchangeability of parts put the science of rifle manufacture in a field altogether apart from any other branch of science and engineering. Hundreds of gauges were therefore required, as many as 120 being needed for the body alone, and although in England the inspection of factory-made rifles proceeded fairly smoothly, the experiences with American contractors illustrate the difficulties inherent in securing interchangeability.[4] The manufacture of the gauges caused great difficulties. The Royal Small Arms Factory was unable, when the peddled scheme was initiated, to produce the very large number required and the delay[5] in output of peddled rifles was due to no small extent to the endless troubles caused by the manufacture of inaccurate gauges by private firms.[6]

Manufacturing difficulties were considerable, especially in the case of major components, as for instance, the body, for which some 250 operations were required. The rifle had been evolved for production at the Small Arms Factory rather than by the trade, with the result that many of its parts were of a peculiarly special nature. Thus, for instance, in the manufacture of screws, the number of threads per inch and the shape of the screw thread were of the Enfield standard, and taps and dies were therefore of special manufacture, and careful gauging was necessary. Experts were accordingly firmly convinced that the service rifle could not be made outside the old-established rifle factories, and the failure of the new works served to give weight to the contention.[7]

Many of these manufacturing difficulties arose from the complex and special nature of the service pattern of rifle. The R.S.M.L.E. (·303 in.) rifle, which was the service rifle at the outbreak of war, was made to a design built up gradually at Enfield with a view to the special facilities at that factory rather than to simplicity of manufacture, to complete efficiency, rather than to speed in production. The ·276 in. pattern (known as the 1914 rifle) which was to have

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[1] See below, p. 60.

[2] *e.g.*, the average life of a grinding wheel was 3,000 barrels. *Ministry of Munitions Journal*, No. 21.

[3] See pp. 9, 60.

[4] See above, pp. 45–47.

[5] See below, p. 59.

[6] Hist. Rec./R/900/12.

[7] See above, pp. 8, 30; Hist. Rec./R/1420/21.

superseded it in the summer of 1914, was far simpler to produce and had been evolved to secure great accuracy and a low trajectory, as a result of experience in the South African War. This pattern was, however, kept back by reason of its tendency to burst if the ammunition was fired when the rifle was heated up. With all its manufacturing difficulties, the R.S.M.L.E. rifle was, therefore, retained in British production throughout the war and proved itself to be a very good pattern for general use. The simpler low-trajectory type was, however, modified for American manufacture, being used with the ammunition of the ·303-in. rifle. The American rifle was designed in a drawing office with a view to simplicity of manufacture ; nevertheless, its production was not so successful as that of the British pattern, and the standard of interchangeability remained a matter of great difficulty. In fact, years of experience, by which British firms benefited in making the more complex type of rifle, outbalanced the advantages gained by introducing a simpler pattern.

(b) LABOUR PROBLEMS.

Experience with contractors in the United States illustrates the importance of the human factor in the production of rifles, for even where the shops were roomy, machinery new, ample and good, and the theory of organisation sound, the quality of work undeniably suffered either through lack of intelligent supervision or previously trained workmen, or through ignorance of requirements.[1] In Great Britain although the manufacture was in the hands of capable people who had long experience of rifle work, and the quality of the finished article was consequently high, expansion of output was seriously retarded not only by the general scarcity of labour but chiefly because of the demand for specially skilled men.[2] Employees engaged on rifle manufacture may be generally grouped into (*a*) supervisors, (*b*) gauge makers, (*c*) toolmakers and section fitters, etc., (*d*) machine hands, and (*e*) specialists. "It is certain," wrote Colonel Halse, "that the supervisory staff must be not only engineers but also experienced rifle-makers. This was, I consider, clearly proved in the case of the firms which attempted to make rifles and failed and in the case of the American firms."[3] The gauge-makers had to be men of the highest skill if interchangeability was to be ensured.

In some cases the tolerations allowed on the components were ·001 in. and ·0005 in. and this allowed no errors in gauges, which were from the nature of the work subject to much use and therefore wear. It was also essential that toolmakers, etc., should be men of experience and knowledge of requirements. The training of men obtained from outside at the Royal Small Arms Factory led to the production of a large amount of scrap and to delay in output. The machine hands were the easiest class to train quickly and successfully, but the specialists, such as barrel setters and viewers, stock finishers and fitters, barrel

[1] See above, p. 45. D.G.A.T.3.

[2] (Printed) *Weekly Reports*, No. 10, II, (2.10.15) ; No. 11, II, (9.10.15) ; No. 15, II, (6.11.15). Contracts/R/2525. See above, p. 4.

[3] Sec./R.S./135 B/1.

drillers, riflers, sight adjusters, assemblers and finish filers took a great deal of training,[1] and it was at times almost impossible to obtain this class of labour. For instance, in March, 1915, lack of machinery and mechanics was the great difficulty at Enfield; in October, 1915, the Machine Tool Committee found it necessary to lend the Standard Small Arms Company 25 men to help at a critical time; and in December, 1917, the reduced output of the London Small Arms Company was attributed to the shortage of tools for machines, brought about by the loss of tool makers; and in 1918 the lack of skilled[2] workers, especially gauge-makers, was exceedingly serious.

In all grades of labour the training classes showed many to be unfit for the work. During September and October, 1914, the London Small Arms Company had to discharge for incapacity 108 of the extra 521 men taken on, and in June, 1917, the Superintendent at Enfield complained of the large proportion of men found to be physically incapable of work; the older men produced a smaller output and while there was an incessant demand for men of military age to join the Colours, the use of women was, owing to the highly specialised nature of the work, considerably restricted.[3] For instance, in barrel setting, a most important operation and one involving a very high degree of skill which could only be obtained after extensive training, women were tried but were only successful up to a certain point and generally speaking did not make efficient barrel setters.

Some trouble was experienced from restriction of output. In June, 1915, the bolt fitters at the London Small Arms Company were reported to be very slack. During the November, 1914, negotiations for an increase in wages, the men at the same factory "held back and did not work their full capacity, presumably with a view to forcing our hands and substantiating their claim."[4]

Exhaustion, excessive overtime, periods of abnormal sickness, medical examinations, the issue of calling up notices, the introduction of the Derby scheme, the abolition of leaving certificates, inducements held out by private firms, and strikes,[5] contributed to unsettle the work-people and affect output adversely.[6]

(c) The Problem of Development.

The special difficulties therefore of rifle-making cumulatively served to render impracticable a very natural method of meeting exceptional demands, viz., the erection of new factories. "Past experience has shown that to start up a new factory for the manufacture of rifles . .

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[1] Sec./R.S./135 B/1.

[2] 94/R/14. Hist. Rec./R/1420/21. C.E. 1949/3. (Printed) *Weekly Reports* No. 12, II, (16.10.15); No. 120, XI, (1.12.17).

[3] 94/R/74. D.G.O.S./Enfield/23.

[4] 94/R/149. 94/R/74; (Printed) *Weekly Report* No. 7, II, (11.9.15).

[5] The net loss resulting from strikes in May, 1917 was 3,798 rifles; (Printed) *Weekly Report* No. 93, VII, (26.5.17).

[6] (Printed) *Weekly Reports*, No. 11, II, (9.10.15); No. 20, II, (11.12.15); No. 80, V, (17.2.17); No. 91, VII, (12.5.17); No. 93, VII, (26.5.17); No. 95, VII, (9.6.17); No. 120, XI, (1.12.17); No. 148, X, (29.6.18); No. 149, X, (6.7.18). 94/R/74; Hist. Rec./H/1420/2; C.E. 1949/3.

is a most difficult undertaking and one which leads to excessive delay, as for example . . . the American rifle contracts and the Standard Small Arms Company."[1] For instance, the Remington Company's factory at Eddystone which had plenty of space, modern machinery, an efficient management and good staff, but no experienced workmen, took a year from the placing of the first contract to produce 200 rifles a week, while the Standard Small Arms Company which never produced a complete rifle were always in difficulties with regard to finance and "instead of following the methods at Enfield as closely as possible . . . branched out into a number of costly experiments which were continually found to be failures."[2]

The peddled scheme as first started in 1915 was slow in becoming productive and was necessarily delayed by the difficulties of inexperienced makers. The great advantage of the rifle component pool, which superseded the scheme in 1916, lay in the fact that it provided a central depôt for the reception of any quantities of any parts produced by private firms as well as for the surplus output of rifle factories and gave opportunity for the use to its utmost extent of such machinery as, owing to the absence of essential units, would not otherwise be working at its full capacity. It also proved "most valuable to have a big banking account upon which one can draw for placing components so that it may be possible to place [orders for] similar components with more than one firm and thereby avoid complete discomfiture by breakdowns."[3]

Quite apart from the impossibility of providing a number of distinct technical staffs, the collection into one centre of suitable local machinery, as distinct from the purchase of complete plants, was found to be valueless because, while arrangements could be made for the manufacture of easier components, there was no machinery available for the manufacture of the major components which were the "bottle-necks" in supply.[4]

Thus, apart from the Standard Small Arms Company's production, which was insufficient, the peddled scheme was not able to provide for the manufacture of those components, such as the body, through lack of which rifle assembly was restricted. To meet this demand the capacity of the Royal Small Arms Factory had to be very considerably extended, and taking into account the long delay before the scheme became productive, and its expense, the results obtained from the rifle component pool, apart from the supply of parts needed for spares and repairs, cannot be regarded as absolutely satisfactory. "I feel confident," stated Colonel Halse, "that had the plant which was at the disposal of the Standard Small Arms Company been removed either to the Royal Small Arms Factory or to the Birmingham Small Arms Company in June, 1916, the results attained, so far as new rifles are concerned, would have been considerably better and that the rifles would have been much cheaper."[5] Manufacture under the scheme was comparatively expensive.[6] Moreover, the ultimate success of the firms was most

[1] D.D.G.E./E.M.3/848.
[2] Hist. Rec./R/1400/21.
[3] D.D.G.E./E.M.3/848.
[4] See above, p. 25.
[5] Hist.Rec. /R/1400/21.
[6] See below, p. 66.

uncertain. For instance, the contract placed with the British Gun Barrel Company for 25,000 barrels in November, 1915, produced, by December, 1918, between six and seven hundred incomplete barrels only.[1]

The ideal method, therefore, of increasing output was the extension of existing rifle factories.[2] In the first place, it made for economy of staff. In a single factory, however large, the thoroughly trained staff had the widest possible scope for the continuous exercise of their special skill and experience, a result impossible in widely separated works. Secondly, it made for quicker expansion of output. Whereas in the equipping of a new factory the beginning of output was limited by the completeness of the machinery, as in the case of the Eddystone factory, the extension of existing plant was largely a matter of continual strengthening of the weaker operations. For instance, to enlarge the capacity for body making, instead of some 250 sets of tools, etc., sufficient only might be required for the strengthening of, say, 20 or 30 operations. Again, where plant was to a certain extent unbalanced, if there were insufficient machines for one operation it was possible to work a single machine for very long hours under specially arranged conditions to obtain from it a greater output, thereby not entirely destroying the capacity of the full plant to manufacture this component, although sufficient machines for operations were not available. This plan was largely adopted at the Royal Small Arms Factory in the early days of the war. Whole lines of shafting were run during the dinner hours to keep one machine at work, and special arrangements at week ends were made for the sake of single operations where these were affecting the output. Such arrangements were, of course, possible in connection with any such plant, but could not be employed in joint connection with two factories.[3]

Against the concentration of manufacture in a few large works there was, however, one considerable objection, viz., the risk of fire, where wooden parts were manufactured. In particular, the "making-off" of the butt gives rise to great quantities of fine dust and the fire-risk in this operation is thus greatly enhanced. This work was undertaken in Birmingham, London and at Enfield, and in order to establish a margin of capacity in case of the destruction of plant by fire at one of these three places, a contract for rifle fore-ends was arranged with a new firm (Messrs. Whitehead) whose plant could upon emergency have been worked by labour drawn from any old-established works which might have been destroyed. It was with a similar object that a margin of deliveries was obtained by placing orders for butts with Messrs. Riley, billiard-table makers.

The possibilities of extension were, however, somewhat limited. By the middle of 1915, the London Small Arms Company had covered practically all available land,[4] and further extensions at the Birmingham Small Arms Company's works were devoted to machine gun manufacture;[5] leaving the bulk of the extensions to be carried out at Enfield.[6] The

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[1] 94/R/389; P.M./R/2226.
[2] Cf. p. 56.
[3] D.D.G.E./E.M.3/848.
[4] Contracts/R/2524. Chap, I, p. 7.
[5] Chap. I. Chap. II.
[6] Chap. II. Chap. III.

methods employed there, however, while calculated to produce excellent results, were not specially suitable for rapidly reaching the manufacturing stage, and geographically the factory was at a disadvantage. It was especially open to attacks from the air, and the diminished output in July, September and October, 1917, was directly traceable to raids.[1] Moreover, the works were difficult of access. The few houses in the neighbourhood were occupied by the permanent staff: the proximity of the Royal Gunpowder Factory and other factories prevented building,[2] and many of the staff had to travel to and from town each day to the detriment of the quality of work. The district was also liable to floods.

II.—Progress in Supply.

After the decision in April, 1915,[3] to make use of the Remington (Eddystone) Company's capacity, no new sources for the supply of complete rifles were tapped, and except for the orders placed under the peddled scheme the work from the middle of 1915 lay not so much in arranging contracts as in taking steps to anticipate and, if possible, to exceed the maximum output which the various plants had been arranged to produce and to secure as large a stock as possible. The value of a large stock was proved at the time of the German offensive in 1918, when the losses were met from store without causing the dislocation which would have resulted had the rifle factories been called upon suddenly to increase output.[4]

The successful administration of rifle supply was considered to be dependent upon two conditions. Firstly, it was regarded as essential that the headquarters staff should include practical engineers skilled in reproductive work to very fine limits. Secondly, unity of control over the Royal Small Arms Factory and contractors was considered absolutely necessary to successful administration in that it provided a direct and speedy means of applying experience gained in the Factory to the manufacturing difficulties of the firms. Many advantages were also obtained through the Ministry's establishment of a system of close co-operation between the various departments dealing with raw materials, labour or machine tools and the supply branch, and between the contractors and the supply officers.[5]

The S.M.L.E. rifle proved a thoroughly satisfactory weapon in the field, and but few alterations in pattern were made during the war. On the recommendation of the technical committee appointed in June, 1915,[6] certain simplifications were accepted, viz., the abolition of the cut-off, aperture and dial sights and the omission of some of the lightening holes,[7] and other minor alterations were authorised at intervals. Various new pattern rifles were submitted, but these displayed no special merits and would have been rejected in any circumstances. The production of an automatic rifle for use with the bayonet excited considerable interest, but the attempted manufacture of the Farquhar

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[1] (Printed) *Weekly Reports*, No. 8, II (18.9.15); No. 100, VII (14.7.17); No. 108, VII (8.9.17); No. 111, VII (29.9.17); No. 112, VII (6.10.17).

[2] Cf. p. 5. [3] See above, p. 11. [4] Cf. p. 34.

[5] See above, pp. 16–17. [6] See above, p. 9.

[7] The cut-off was retained in rifles for use of the cavalry (C.R. 1441, 94/R/392).

Hill rifle was the only practical outcome.[1] For this rifle alone new national factories were established; but manufacture was discontinued before a single rifle had materialised from these schemes.

(a) Progress and Inspection.

The quality of the finished article was ensured by the Chief Inspector of Small Arms, and owing chiefly to the slow expansion of output and the experience of the rifle makers, the calls on the inspection staff were not excessive. There was never any uncertainty as to the number of rifles required, the training of the inspection staff was able to keep pace with the demand and the organisation was comparatively effectual except that owing to differences in manufacturing methods introduced by the necessity for different methods in gauging, the co-ordination between rifle production in the London and Birmingham areas was not entirely satisfactory.[2]

In the last part of 1916, on the representation of the Birmingham Small Arms Company, some slight relaxations in inspection were agreed by the Chief Inspector of Small Arms and approved, and between August, 1916, and March, 1917, rifles were accepted both from the Birmingham and from the London Small Arms Company with barrels which though taking the ·305 in. rejected the ·3055 in. plug.[3] This gave a toleration greater by ·0005 in. than was previously allowed.

In order to speed up production the Ministry of Munitions organised, both in the United States[4] and in Great Britain, a small staff appropriately known in the former country as quantity inspectors, whose function it was to visit manufacturers, and through discussion on special and local difficulties to suggest possible improvements in manufacturing methods and to secure government assistance in the matter of material, machinery or labour.

Prior to 1915 much of the work in hastening up firms had been left to the Chief Inspector of Small Arms, whose staff was already sufficiently overworked. The new arrangement, therefore, of delegating this task to officers borne on the strength of the supply branch afforded him some relief and was specially valuable in connection with the peddled scheme where the contractors were unfamiliar with standard processes.

Only occasionally were the Inspection Department led to complain "that the subordinate emissaries of the supply branch were inclined to stray away from their proper function of speeding up output and gave manufacturers a false idea as to what was acceptable."[5]

The plan of investigation on the spot also assisted the supply branch in estimating future output, especially in cases where delivery depended upon receipt of machinery from other firms. It was undeniably advantageous to secure a personal relation between supply branch and contractor. Moreover, the instruction given from time to time by the engineers from headquarters met with the greatest success in overcoming practical difficulties, as, for instance, was the case in respect to assistance given to Messrs. Singer in spring manufacture and to Messrs. Riley in regard to rifle butts.

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[1] See above, p. 34. [2] Hist. Rec./H/900/12.
[3] 94/R/268. Hist. Rec./H/1420/2.
[4] See above, p. 41. [5] Hist. Rec./H/900/2.

(b) ECONOMIES IN MANUFACTURE.

Wherever possible labour and time-saving machinery was introduced and material economised. For instance, malleable iron castings were used as an alternative for certain components for which this metal was considered strong enough. Again, in order to obtain increased production from a given floor space and a given number of machines, higher cutting speeds and the use of higher grade steels were introduced. Improved fixings were brought in and the use of double fixings whereby two components were milled at the same time was extended. Reversible fixings and drilling jigs and self-tightening chucks were also introduced.[1] Presses were used in connection with the manufacture of certain components which had been previously milled. To help the older men attempts were made at the Royal Small Arms Factory to design special machinery.

By these and similar plans the manufacturing difficulties, which resulted from the policy of extending rather than building new factories, were to some extent mitigated.

(c) THE SUPPLY OF LABOUR.

The policy of building extensions to shops rather than new factories helped also to relieve the problem of training labour in so far that new hands were under the constant supervision of the highly trained experts and were therefore more likely to make good in a short time.

The Government Instructional Factories provided a certain amount of semi-skilled labour for rifle shops, but in July, 1918, owing to the impossibility of obtaining from any source parts, especially jigs and gauges, on which to train labour, the Training Section was temporarily unable to render any assistance.[2]

To cope with the demand Sunday work was allowed soon after the outbreak of war, but was limited as far as possible. Concessions in respect of the hours of employment for boy labour were also made, and in the case of the London Small Arms Company continued until 1918.[3]

Volunteer workers were also employed, and while the London Small Arms Company were averse to the experiment, fearing the effect on the temper of the regular employees, at the Royal Small Arms Factory in September, 1915, there was a considerable number whose industry produced a good result. In October, 1918, there were 265 volunteers at Enfield.[4]

Women labour was also introduced where possible. In some of the more specialised processes women were not found to be successful, for instance, as barrel setters, but where, as in the case of barrel viewing, they were quite equal to men, they were largely employed.[5] A large number were employed usefully on unskilled work. Women were introduced at Enfield in April, 1916, and by April, 1918—1,629 were employed.[6] At the London Small Arms Company there were no women working in August, 1916, and although a certain number were

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[1] *Ministry of Munitions Journal*, No. 21.
[2] D.D.G.E./E.M.4/437.
[3] C.E. 641/13.
[4] D.D.G.E./E.M.4/554.
[5] See above, p. 57.
[6] D.D.G.E./E.M.4/433.

subsequently taken on, the scheme for largely increasing women labour had been held up owing to lack of accommodation and to opposition from the contractors, and had not materialised when the Armistice was signed.

(*d*) Supply of Material.

While from the outset all wood used in the manufacture of rifles was obtained from Enfield at a suitable charge,[1] the rifle-making factories purchased all other materials from the trade. The firms, therefore, in order to make advantageous purchases of raw material as far ahead as possible, were anxious to secure long contracts, whereas under the running contracts both the Birmingham and London Small Arms Companies were subject to three months' notice of termination and were consequently unable to look far ahead. Both firms, therefore, were given authority at various times to purchase raw material to cover output farther ahead than the contract warranted, as, for instance, when on 22 December, 1915, the London Small Arms Company were authorised to buy sufficient raw material to cover their output up to 31 December, 1916. Similar permission was given on 9 September, 1916, for material up to 30 June, 1917, and to the Birmingham Small Arms Company in May, 1915, for material up to 31 March, 1916.[2]

With the increasing shortage of raw material permission was limited, as when the London Small Arms Company were not allowed to purchase more brass and brass-screwed wire than was necessary for the current contract.[3]

In connection with the peddled scheme,[4] at the commencement it was arranged that, in order to assist contractors, the Superintendent of Waltham and Enfield should order raw material in excess of his requirements and issue free to components contractors who wanted it. There were, therefore, two classes of contract, the one for articles made from material which was supplied by the contractor and inspected by the Chief Inspector of Small Arms, and the other for articles manufactured from material which had been issued free from Enfield and inspected by the Superintendent before issue.[5] In the latter case sufficient material was issued to cover the contract plus a certain percentage for wastage. The system of free issue was however abandoned almost immediately on the introduction of the rifle component pool.[6] It was retained for a short time only in the case of a few early continuation contracts.[7] In some cases where contracts were cancelled, materials supplied by the manufacturer were taken over by the Government,[8] and eventually all component contractors drew their material from Enfield on payment.[9]

Later, recoveries were made where possible. Contractors who found the amount of material allowed insufficient were made to pay for the balance required to complete the contract, and the same plan was adopted where material rose in price between the time when the contract was placed and the date at which later, and what were

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[1] See below, p. 66.
[2] 94/R/457; 94/R/933; 94/R/30; 94/R/716.
[3] 94/R/933.
[4] See above, p. 18.
[5] 94/A/304.
[6] Hist. Rec./R/1420/12.
[7] 94/A/756.
[8] 94/A/483; 94/A/321.
[9] D.D.G.E./E.M.3/949.

considered unnecessary, issues were made as, for instance, in a case where steel had been supplied at 75s. per cwt., but was charged at 115s. per cwt. for an additional amount applied for.[1]

In fixing the cost the price per cwt. and the number of components per cwt. were given, so that a suitable weight of material was charged against each bill, a plan adopted owing to the number of light components, e.g., the spring extractor, of which 25,600 were produced from 1 cwt. of steel at a cost of ·0582d. each. Finally, in the spring of 1918, it was decided that contracts should show the price per cwt. at which material was to be issued, and the price per component to be recovered, which was fixed at the value of material as found from the Royal Small Arms Factory factor plus 20 per cent., and calculated to the nearest round figure each or per dozen or hundred as was most suitable.[2]

In the autumn of 1916 a "break" clause was inserted in most of the contracts. Under this clause in all contracts extending over a period of three months or upwards, the Minister reserved to himself the power to terminate his liability at any time by giving 14 days' notice if the war should terminate or show signs of early termination. If necessary, contractors were to complete articles in course of manufacture and to cease manufacture at the end of the notice, and, under certain conditions, the Ministry was prepared to take over at cost price material or components unused owing to the exercise of the power of termination, and also to indemnify contractors against commitments incurred for the purchase of material.

By 1917 the general policy in regard to orders was that, whereas at the Royal Small Arms Factory it was found advisable to place orders for material as much as twelve months ahead, the rifle-making factories were not guaranteed material for more than six months.[3]

(*e*) COST OF RIFLE SUPPLY.

Prior to the outbreak of war the trade price for rifles was 71/3 each, but to meet the rapid advance in the cost of materials, the addition of oil bottles and pull throughs and the necessity for overtime payment, the price on the first contracts was raised to 75/-.[4]

Both the Birmingham and London Small Arms Companies pressed that the contract price should be revised in the event of a recognised increase in wages or cost of material, and early in 1915 the former point was conceded. The price per rifle produced by the Birmingham Small Arms Company was increased to 76/6, "subject to revision in the event of the contractor being compelled to pay any further general advance in wages resulting from a general agreement between the Employers' Federation and the Trade Unions concerned."[5] Later, the clause "subject to the approval of the Minister of Munitions" was added, and, in the case of the London Small Arms Company, any increase in the price of fuel beyond 10 per cent. was to be taken into

[1] D.D.G.E./E.M.3/937. [2] D.D.G.E./E.M.3/949.
[3] D.D.G.E./E.M.3/707.
[4] HIST. REC./H/1420/2. Contracts/A/2623A. For price of rifles made in the United States, see above, p. 11.
[5] Contracts/G/1786. HIST. REC./H/1420/2.

account.[1] Claims in respect of losses incurred through compulsory increases in wages were not met by an addition to the price per rifle, but were usually dealt with by the grant of a lump sum on the completion of contract, but where, as in the case of the London Small Arms Company, a firm was so weak financially as to be unable to continue manufacture, the existing contracts were cancelled, a grant sufficient to cover the year's losses allowed and a fresh agreement made.[2] The same company was also paid about £29,730 for losses due to increase of wages in the period 2 April, 1917, to 31 March, 1918.[3]

In the case of Messrs. Herbert's, who found it difficult to supply the information needed to complete the official form, a sum equivalent to what it had cost the Royal Small Arms Factory in meeting increases in wages over a similar period was allowed.[4]

The cost of producing rifles and components was specially heavy where firms were inexperienced, chiefly owing to the large number of rejections resulting from the insistence on absolute interchangeability of parts. In consequence, financial failure was not uncommon. Where, as in the case of the American firms, successful negotiation was impossible owing to the attitude of the contractors, the Government was prepared to take over and run factories, but the course preferred was that adopted in the case of the Standard Small Arms Company in 1917, namely, the grant of a loan secured by mortgage.[5]

During and after 1916 most of the material was issued at fixed prices, through the Superintendent at Enfield, and, except for adjustments due to certain modification in pattern,[6] the price per rifle did not vary to any very great extent. For instance, at the Royal Small Arms Factory the estimated cost in June, 1916, was £3 5s. 0d. per rifle as compared with £3 18s. 5d. in June, 1918.[7] The latter figure included depreciation and overhead charges, and it should be noted that, although the cost of rifles made from peddled components was considerably higher than those made entirely at Enfield, in the estimates of the price per rifle, completed and ready for issue, no differentiation was made. Rifles made by the Birmingham Small Arms Company cost 75/– each on the outbreak of war and 76/– each in June, 1918.[8] In regard to the peddled scheme the high prices paid were not unreasonable, in view of the fact that many firms had to purchase machinery or arrange for the provision of fixings and gauges. In January, 1916, the prices of peddled barrels at different stages were 13/-, 20/-, 25/- each as compared with 7/-, 7/4½, 7/9½ for the same article made at the Royal Small Arms Factory.[9] In 1918 the cost of peddled rifles was estimated to be 33 per cent. above those made in rifle factories.[10]

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[1] 94/R/457.

[2] 94/R/192; Hist. Rec./R/1420/8; See above, p. 22.

[3] C.C.L./807/473.

[4] D.D.G.E./E.M.3/969.

[5] D.D.G.E./E.M.3/724. See above, p. 30.

[6] e.g. In March, 1918. the Birmingham Small Arms Co.'s rifle was reduced by 5/- owing to the introduction of a new pattern cap backsight. *Order and Supply List* E. No. 129.

[7] 94/R/392. D.D.G.E./E.M.3/1083.

[8] D.D.G.E./E.M.3/1083.

[9] D.D.G.E./E.M.3/106.

[10] D.D.G.E./E.M.3/850.

The payment of a number of grants for the equipment of plant was, however, a considerable charge on Government funds. The earliest grants made to British contractors in 1914 by the War Office to the London and Birmingham and Standard Small Arms Companies[1] were not in any way repayable, but in later contracts arrangements for whole or partial repayments were made.[2]

In America the system of payment in advance of 25 per cent. of the total order, originally adopted by the War Office "to aid and stimulate sources of supply," was, owing to the independent attitude of the contractors, continued by the Ministry of Munitions, but with thoroughly unsatisfactory results.

The total cost, therefore, to the Government of its rifle supply was considerable, chiefly owing to the frequent need for financial assistance for every kind of firm either for the equipment of extensions or to meet deficits incurred through the expensiveness of production of such an accurate weapon.

(f) OUTPUT FIGURES.

During the period August, 1914, to November, 1918, the actual acceptances from English and American sources of supply were as follows :—

	1914 Aug.–Dec.	1915	1916	1917	1918	*Total.*
Great Britain :						
Enfield[3]	51,576	271,856	418,283	640,113	626,330	2,008,158
Birmingham Small Arms Co.	56,416	275,927	435,212	468,547	345,752	1,581,854
London Small Arms Co.	12,101	65,678	99,433	97,012	89,990	364,214
Total	120,093	613,461	952,928	1,205,672	1,062,072	3,954,226
America :						
Ross Rifle Co. .. (Arrivals)	—	2,650	33,476	82,360	—	118,486
U.S.A. .. .. (Acceptances)	—	—	373,282	870,283	—	1,243,565
Total	—	2,650	406,758	952,643	—	1,362,051
Grand Total ..	120,093	616,111	1,359,686	2,158,315	1,062,072	5,316,277

[1] London Small Arms Co., £27,000 ; Birmingham Small Arms Co., £35,000 ; Standard Small Arms Co., £60,000. See above, pp. 5–8.

[2] For arrangements made with the Birmingham Small Arms Co. and London Small Arms Co., see above, Chapters I–III, and for terms granted to the American and Canadian contractors, see Chapters I and IV.

[3] Deliveries from manufacturers under the peddled scheme included as Enfield acceptances.

Although eventually about a quarter of the total supply came from overseas, the original intention had been that America should produce three times the quantity sent, i.e., the bulk of the requirements, and for the first eighteen months of war reliance was placed on this source. Then rifles both from Canada and from the United States proved to be inadequate and unsuitable for use in the field, so that at a particularly difficult time, when the situation in regard to all classes of labour, machinery, and material was full of complexity, it became necessary to change the policy, and in the end the chief credit for the successful arming of the British fighting forces with rifles must be assigned to British organisation and effort.

VOLUME XI

THE SUPPLY OF MUNITIONS

PART V

MACHINE GUNS

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CHAPTER I.

INTRODUCTORY.

I. Types of Machine Gun in the British Service.

The four types of machine gun used by the British forces during the war were the Maxim, the Vickers, the Lewis and the Hotchkiss. Of these the Maxim and the Vickers were in service use when war broke out. They were belt fed guns fitted with water jackets, and could be used for continuous firing. The Lewis and the Hotchkiss guns were lighter types introduced during the war, and were of a nature approaching that of the automatic rifle,[1] from which, however, they should be distinguished. They were not water-cooled, and were fitted with magazines in place of the belt feed. Though unable to stand the strain of a sustained high rate of firing their portability rendered them of special value in offensive operations.

(*a*) THE MAXIM.

The earliest of these four machine guns was the Maxim. A ·45-in. Maxim gun was introduced into the land service in January, 1891. This was succeeded in July, 1893 by a ·303-in. gun, taking ammunition of the same calibre as the service rifle. Later ·45-in. guns were converted to guns of the smaller calibre barrel, with the result that, in 1917, ·45-in. guns were only to be met with in the Colonies, India and Egypt. The average weight of the ·303-in. Maxim was about 60 lbs. without water and the normal rate of firing with Mark VII ammunition was 500 rounds per minute. For this ammunition it was sighted up to about 2,800 yards. It was operated by the force of recoil, whereas the Hotchkiss and Lewis guns were gas-operated, and the Vickers was operated by the force of recoil, assisted by gas.

(*b*) THE VICKERS.

The ·303-in. Vickers machine gun was approved in November, 1912, and was superseding the Maxim when war broke out. With muzzle attachment weighing 1 lb., it weighed 28½ lbs. The rate of fire was 500 rounds per minute, and with H.V. ammunition it was sighted up to about 2,900 yards. The lightness of this gun, as compared with the Maxim, was due to the substitution of a water jacket of light steel for one of heavy gun metal, to a reduction in the depth of the breech-casing and lock, and to a general lightening of parts wherever possible, ejection taking place by gravity through an aperture in the breech casing instead of through a special ejector tube.

Various modifications in the design were introduced during the war. In December, 1914, changes were made in the barrel to increase the accuracy of the gun under the stress of continual firing.[2] In 1915, a

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[1] For the Farquhar Hill rifle see Vol. XI, Part IV, p. 34.

[2] Contracts/G./1669.

light portable tripod mounting, invented in the Machine Gun School in France, was adopted.[1] Changes were made in the form of the cartridge belt, and ultimately an expendible belt, which could be discarded after use, was introduced; but the original belt proved to be the best, except for use in aircraft. A lighter type of gun, suitable for use in aircraft, was approved for the air service in April, 1917.

(c) THE LEWIS.

The ·303-in. Lewis gun weighed 28½ lbs. with its bipod mounting. It was sighted up to about 2,000 yds. for Mark VII ammunition. It was fed by flat circular magazines holding 47 rounds each, which were used both in the field and for air service until 1917, when a Mark II magazine holding 97 rounds was introduced for the air service. The gun had been invented by Colonel I. N. Lewis, of the United States Army, and the European patents, taken out by the Automatic Arms Company of New York, in 1910, had been acquired in 1912 by the Armes Automatiques Lewis. It had been rejected for land service in 1912, since it was then considered undesirable to multiply types; and had also been under trial by the War Office and the Admiralty as a weapon for arming aircraft. Experimental guns for aircraft were ordered in 1913 and again in July, 1914, but they had not then been adopted; guns for land service were ordered in September, 1914, and formally approved in the following October.

(d) THE HOTCHKISS.

The ·303-in. Hotchkiss gun weighed 28¼ lbs. The cartridges were fed into the gun on flat, tempered strips of 30 rounds each. The gun could be operated by one man loading and firing, the speed of fire then being 250 rounds per minute. If a second operator loaded, the speed was increased to 400 rounds per minute. The gun was tested for the Admiralty in 1914, and the first arrangements for manufacture were made by that Department early in 1915.[2] The first military demands were received in January and February, 1916, and were for guns to arm cavalry and tanks. The gun was fitted with a butt-stock for use by cavalry and with a pistol-grip for issue to the Tank Corps, and later for anti-aircraft purposes. An entirely new and much lighter design was submitted by the Société Hotchkiss towards the end of 1917.

(e) ATTEMPTS TO INTRODUCE THE MADSEN GUN.[3]

Several attempts were made to introduce another light machine gun, the Madsen, of Danish invention. This gun was an improvement on the "Rexer," which had been made at Willesden, in 1904, supplied to various foreign Governments, and successfully used by the people of Natal in suppressing the Zulu rebellion of 1906, but rejected by the British military authorities. The Madsen had been under consideration by the Small Arms Committee since December, 1913, and was still under trial for use in aircraft when war broke out. The first bulk order

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[1] HIST. REC./R./1410/1. [2] See below, p. 15. [3] HIST. REC./H./1410/1.

was placed with the Danish makers by the Admiralty in May, 1915, and the use of this type was recommended shortly afterwards by the Commander-in-Chief. The gun was very light, weighing 16½ lbs., or with the spare barrel, which might have to be carried into action, 21½ lbs. Its chief advantage was its capacity for continuous fire; its main disadvantages were noise and flash and the difficulties experienced in obtaining deliveries from Denmark and in establishing a factory in England, whilst the production of the other two types of lighter guns, the Lewis and the Hotchkiss, was being fully organised.[1] Military opinion was consistently opposed to unnecessary multiplication of types, if sufficient numbers of the standard patterns were forthcoming. Accordingly, in January, 1916, the Army Council notified that they did not propose to make use of Madsen guns. Several new trials of the gun for use in tanks and aircraft took place during 1917; in these, objection was taken to the flash, the shape of the magazine and the inability to fire upside down, but the gun was then considered superior to the Lewis gun in nearly all respects.[2] In January, 1918, when it seemed practicable to transfer to England Danish plant and labour for making the Madsen gun, and desirable to prevent their output from falling into enemy hands, the Government decided that machine gun supplies should be supplemented by Madsen guns.[3] Negotiations did not, however, result in favourable financial terms, and in the opinion of the Master-General of the Ordnance it was undesirable to obtain British rights in the gun, if they could not be cheaply purchased, while the possibility of acquisition by the Germans seemed to him inconsiderable.[4] Finally, in April, 1918, the Army Council decided against the purchase of the plant and patent rights, chiefly grounding their opinion on the fact that the large numbers of Lewis guns then in use precluded their replacement by Madsen guns, even though it might be argued that, gun for gun, the Madsen was superior to the Lewis.[5] The second project for manufacturing this gun was accordingly abandoned;[6] and shortly afterwards systematic trials of the various types of mobile machine guns, which were carried out at Bisley Ranges, set the various types tested in the following order: (1) Lewis, (2) Light Hotchkiss, (3) Madsen, (4) Heavy Hotchkiss, (5) Berthier.[7]

II. Development of the Demand.

(*a*) Growing Importance of Machine Guns.

At the outbreak of the war, the machine gun was regarded by British authorities as a weapon of opportunity rather than as an essential munition of war. The number allotted to each battalion was only two. This number was soon increased, and, by June, 1915, machine gun requirements had been raised to eight per battalion,[8] and a project for forming machine gun companies was under discussion. It was originally customary for each battalion to make what use it

[1] See below, Chap. II.
[2] D.G.M.D./R./315.
[3] D.D.G.E./E.M. 1/734.
[4] M.C. 516.
[5] 94/G./220.
[6] See below, p. 18.
[7] Hist. Rec./H/1410/1 Appendix VII.
[8] Hist. Rec./R/1000/1.

could of its own small machine gun equipment. Later the value of co-operation was appreciated, and at the close of 1915 the War Office statement of machine gun requirements was based on an establishment of sixty-four guns per brigade. In recommending this establishment, the Commander-in-Chief suggested that sixteen should be formed into a brigade machine gun company, four should be attached to each battalion as a battalion machine gun section, and two of lighter type should be attached to each company of the battalion.[1] This principle of co-ordination was adopted and developed. The importance of the machine gun as a weapon of defence and offence in land service was still further emphasised in the later stages of the war by waning man power.[2]

The development of the fighting aeroplane and the invention of the tank gave fresh opportunities for the employment of the machine gun. The designs of the Vickers and Lewis ground service machine guns were adapted for use in the air service; the Hotchkiss was employed for tanks, except for a short period from November, 1916, to April, 1917, when it was replaced by the Lewis gun. With the perfecting of the interrupter gear mechanism, whereby a machine gun could be fired through the propeller, rapid developments in the firing power of aeroplanes took place. The enormous development in aerial warfare which was planned for 1918, called for an exceedingly large supply of machine guns, for not only was the number of flying squadrons in France increased by this programme from 47 to 86,[3] but the number of guns per machine was also augmented. Machine guns were also increasingly used for anti-aircraft work as a defence against attacks on troops by low flying aeroplanes.

(*b*) Machine Gun Requirements.

The first Expeditionary Force was equipped with machine guns on the scale of two per brigade, and in August and September, 1914, the War Office placed orders for Vickers and Lewis guns in excess of the establishment so that an increased scale might later be offered to the Commander-in-Chief. In October, 1914, the equipment of the proposed new armies on the existing scale raised the requirements to 1,451 guns, with due allowance for maintenance and training. Additional requirements which were formulated in November, 1914, for brigade and divisional batteries for equipping the second line Territorial Force and a simultaneous doubling of the scale, brought this figure up to 2,214. In May, 1915, General Headquarters asked for four Lewis guns per cavalry and infantry unit in addition to the four Maxim or Vickers guns then required.[4] On 1 June, 1915, the actual number of machine guns on service in all theatres of war was 1,330, leaving an immediate deficiency of 60 per cent. (2,060 guns), in the equipment of the 30 divisions then in the field.[5] A week later (9 June), it was understood that the number of machine guns ultimately needed would be over

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[1] Hist. Rec./R/1000/19.
[2] D.D.G.(C.)/C.M.G./168.
[3] Hist. Rec./H/1960/3.
[4] Hist. Rec./R/1000/119, pp. 39–40.
[5] Hist. Rec./R/1000/1

13,000,[1] the requirements upon which the Ministry of Munitions first worked being for 13,220 guns by March, 1916, together with some allowance for second line units.

This requirement was based on the scale of eight machine guns per battalion. Fresh War Office requirements based on the establishment of 16 machine guns per battalion, which had been suggested in November, 1915, were formulated at the beginning of January, 1916. This demand was stated for each month, the numbers expanding as units were mobilised, until establishments were expected to be completed, viz., in May, 1916, when 70 infantry divisions and 10 cavalry divisions were to be in the field. In all, 8,471 Vickers and 8,901 Lewis guns, or a total of 17,372 were required. Wastage was calculated at the rate of 6 per cent. monthly, and the allowance for wastage on guns in use brought the whole requirement up to 13,305 Vickers, and 14,503 Lewis guns, or a total of 27,808 for the year 1916.[2] Moreover, the demand for Hotchkiss guns to supply cavalry and tanks began with a requirement for 800 guns in January, 1916, and was raised to 1,300 in February, and again to 1,700 in March.[3]

On arrangements already made, it was expected that Lewis and Vickers gun equipments should be completed by June and August, 1916, respectively. From these dates onwards, the supply necessary to maintain the guns in use would be approximately 534 Lewis and 508 Vickers guns per month ;[4] but requirements were again increased before the output anticipated had been realised. In June, 1916, the complete establishment was stated as 8,895 Vickers, 18,771 Lewis, and 1,700 Hotchkiss guns for cavalry, while an additional 375 Hotchkiss guns were required for tank supply.[5] The number then estimated as likely to be in existence on 31 August, 1916, was 6,720 Vickers, 16,293 Lewis, and 1,737 Hotchkiss guns, and the completion of the establishment was thus deferred till the end of the year.

As soon as this completion was in sight, it became necessary to decide what continuation orders should be placed in order to replace wastage and maintain manufacturing capacity. The War Office desired in July, 1916, that manufacture for the British forces should continue on the following bases :—[6]

Vickers guns, 800 per month, *i.e.*, wastage 533 per month, plus 50 per cent.

Lewis guns, 1,700 per month, *i.e.*, wastage 1,126 per month, plus 50 per cent.

Hotchkiss guns, 150 per month, *i.e.*, wastage 100 per month, plus 50 per cent.

The initial demand for the Hotchkiss was simultaneously raised from 1,700 to 2,400.[7] The surplus output was thus available for the Allies, and in September, 1916, ministerial authority was given for orders for Vickers guns to be placed on behalf of France and Roumania ;[8] but an upward revision of the British requirements in October, 1916,

[1] D.D.G.E./E.M.1/35.
[2] HIST. REC./R/1000/19.
[3] D.D.G.E./E.M.1/193,318.
[4] D.M.R.S. 135.
[5] HIST. REC./R/1400/15.
[6] HIST. REC./R/1400/9, 11.
[7] C.R.4421.
[8] HIST. REC./R/1410/21.

left no surplus of Vickers and Hotchkiss guns before the end of February nor of Lewis guns until April, 1917. During 1917 the surplus capacity was once again absorbed by new demands. Developments in aerial warfare called for corresponding increases in machine gun output, and in July, 1917, the danger of machine gun supplies being inadequate for future aircraft purposes became apparent. Machine guns suitable for interrupter fire on aircraft were needed, not only for the British air forces, but also for France, Italy, Russia and America. At a meeting held on 3 August, 1917, to discuss the prospective requirements of machine guns for aircraft, it appeared that by September, 1918, 4,120 Vickers and 4,000 Lewis guns per month would be required for all services,[1] whereas the estimated maximum supply per month was 3,000 Vickers and 5,000 Lewis guns. The total estimated monthly requirements were not greatly in excess of the total estimated supply, but the proportion of Vickers to Lewis guns was considerably at fault, and since the latter were not suitable for firing through the propeller by means of the interrupter gear mechanism, it was not possible to substitute them for the Vickers guns.

The increase in machine gun requirements continued to be progressive. On 10 December, 1917, revised Royal Naval Air Service and Royal Flying Corps requirements were issued for Vickers machine guns for aircraft. At a conference on machine guns held on 2 January, 1918, it was stated that during the period 24 November, 1917, to 31 May, 1918, deliveries of 23,216 Vickers guns were anticipated, and that requirements over this period, if demands by Allied Governments were to be met, were 25,400 Vickers guns. It had accordingly been decided to increase the Lewis gun output from 1,000 per week to a maximum of 1,600 per week by increments of 25 per week, the total requirements of every type of gun for the above period being 28,424.[2]

Further increases in the demand were expected towards the end of the year. Indeed, the requirements for 1919 exceeded any previous demand. On 23 February, 1918, the Minister wrote :—

> "It is evident that we must make great efforts to increase the supply of machine guns for 1919, and that that must be one of the principal features in our programme for that year. Aeroplanes will make an enormous demand; Tanks will make a very large demand. As infantry personnel diminish, the number of machine guns and automatic rifles required will inevitably increase, very likely double. The artillery will increasingly require machine guns to protect them from low-flying aeroplanes, and it is very likely that others will be required for the defence of aerodromes and depots in rear of the line which will be liable to aeroplane attack. For all these reasons our supplies of Vickers, Lewis, Hotchkiss and other machine guns will require to be developed on a great scale."[3]

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[1] These requirements were made up as follows :—
Vickers : 2320 R.F.C. ; 500 R.N.A.S. ; 800 Land Service ; 500 Allies.
Lewis : 1400 R.F.C. ; 400 R.N.A.S. ; 2,000 Land Service and wastage ; 200 Allies.

[2] D.M.R.S. 135 M.

[3] M.C. 555.

A programme was accordingly drawn up for an output of 138,349 machine guns (*i.e.*, 53,952 Vickers, 65,230 Lewis, and 19,167 Hotchkiss) during the year 1918, and 192,000 machine guns (*i.e.*, 86,000 Vickers, 86,000 Lewis and 20,000 Hotchkiss) during the year 1919. In April, 1918, it became necessary to increase the proportion of land service guns, as the reserve of Vickers and Lewis ground guns had been almost entirely depleted, and, in addition to providing for wastage and bringing battalions to the authorised establishment, losses sustained in the German advance had to be made good. Again, in August, 1918, revised statements shewed the total requirements for Vickers and Lewis guns for the 12 months ending June, 1919, to be as follows :—[1]

	Ground.	Air.		Total.
	British.	British.	Allies.	
Vickers	18,000	34,970	7,200	60,170
Lewis	36,000	20,020	6,000	62,020

Finally the requirements of aero-guns for the Allies were again increased in September, 1918, bringing their total demand up to 600 Lewis and 700 Vickers guns monthly.[2]

III. Administrative Organisation for providing Machine Guns.

(*a*) Arrangements Under the War Office.

Under the War Office, the responsibility for the design and supply of machine guns and their ammunition, together with bicycles, transport vehicles and optical stores rested with section A.3. of the Directorate of Artillery, which was under the Master-General of the Ordnance.

(*b*) Supply Organisation under the Ministry.

When responsibility for the supply of these stores was transferred to the Ministry of Munitions on 5 June, 1915, machine guns were dealt with by a section under Mr. (later Sir Ernest) Moir, which formed part of the branch of the Munitions Supply Department controlled by Mr. (later Sir Eric) Geddes, Deputy Director-General (C). Other sections of the same branch were responsible for rifles and other stores and small arms ammunition, including the ammunition for machine guns, and later, for the administration of the Royal Ordnance Factories. Under a reorganisation of the Munitions Supply Department, which took place in January, 1916, a separate Deputy Director-General (E), Mr. (later Sir Arthur) Duckham, was appointed in charge of machine guns, small arms ammunition, rifles and salvage, and the administration of the Royal Small Arms Factory, Enfield. In the middle of 1916, Deputy Director-General (E)'s branch became part of the Ordnance Supply Department under Sir Charles Ellis as Director-General, Mr. Alexander Duckham being responsible under him for machine guns, rifles, and small arms ammunition.

[1] D.M.R.S. 135 M. [2] *Ibid.*

With the formation of the Munitions Council, August, 1917, the Small Arms and Machine Guns Department, of which Colonel S. C. Halse, Deputy Superintendent of Enfield, was appointed Controller in February, 1918, became part of Group G (Guns), and in January, 1918, when this group was amalgamated with Group P (Ammunition), it formed part of the new Group O (Ordnance).

(c) The Administration of Design and Inspection.

Responsibility for the design of machine guns remained with the War Office until the formation of a Design Department within the Ministry in December, 1915. Machine gun design then fell to Deputy Director-General (S), Lieut.-Col. F. J. Byrne, advised by the Munitions Design (Small Arms) Committee, which succeeded the former War Office Small Arms Committee. Similarly, the inspection of machine guns was administered by a Deputy Director-General (Z) within the Inspection Department of the Ministry. The inspection authority was originally responsible for the repair of machine guns returned from overseas until the autumn of 1917. The numbers to be dealt with were then increasing rapidly, and this work was transferred to the supply officers, in order to provide the facilities for rapid output, which did not exist within the inspection shops.[1]

[1] M.C. 33

CHAPTER II.

THE PRODUCTION OF INDIVIDUAL TYPES.

I. Maxim Gun Production.

The Maxim gun was obsolescent at the outbreak of war, but those in service were retained. The introduction of Mark VII ammunition had made it necessary to strengthen the lock. This work was in progress when war broke out, and there were then insufficient strengthened locks to provide spares for all the guns on the establishment.[1] The manufacture of spare parts and accessories was carried out at the Royal Small Arms Factory, Enfield. During the first two or three years of the war, the factory also produced comparatively small numbers of complete guns, upon a hand production basis, both for the Admiralty and the War Office. The total output from the factory was 666 guns.[2] Production ceased about March, 1917, when the pre-war policy of abandoning this type of gun for the land service was put into complete effect.[3]

II. The Supply of Vickers Guns.

The Vickers gun, which was to replace the Maxim, had been manufactured on an experimental scale since 1911, but only a little over 100 had been produced before the war.

(a) Supply under the War Office, 1914–1915.

Between August, 1914, and June, 1915, four contracts[4] were placed by the War Office with Messrs. Vickers for a total of 1,792 guns: the first was a starting order placed on 11 August, 1914, for 192 guns, the second on 10 September, for 100, the third on 19 September, for 1,000, and the fourth a few days later for 500 more. There was a provision in the third contract that the rate of delivery should be at 50 guns per week, while ten to twelve had been the rate allowed under the first order.

Deliveries under these contracts were made at a fixed price per gun,[5] and the firm bore the whole cost of extending the factories. In October, 1914, permission was given to lay down plant for making 50 guns a week for the French Government, provided that output for British forces should not be thereby delayed and that the plant should be available for British orders when the French contract was completed.[6] When the Ministry was established, negotiations were proceeding for the payment of a bonus of £50 upon each gun delivered in excess of an average of 50 per week up to the end of December, 1915.[7]

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[1] Hist. Rec./H/170/7.
[2] Hist. Rec./H/1122/101.
[3] D.M.R.S. 135 M.
[4] Contracts/G/1566, 1609, 1669.
[5] See below, p. 21.
[6] Hist. Rec./R/1000/119, p. 39.
[7] Contracts/G/2057.

The firm had failed to keep its promises as to delivery, mainly because of difficulties in obtaining skilled labour. The whole of the 1,792 guns were due by July, 1915, but 1,022 only had been received by that date, although the firm had been instructed in the preceding January that the War Office would take every gun they could produce, in addition to the whole output of the new factory laid down for their French contract until the end of the war.[1]

(b) CONTRACTS PLACED BY THE MINISTRY.

As soon as the Ministry was formed a vigorous and extended programme for securing the numbers of guns required was undertaken. Writing in September, 1915, with reference to Allied difficulties in obtaining sufficient machine guns, Mr. Geddes alluded to the need for a long view in machine gun contracts, since " to create a new output of this class of weapon, one must formulate a definite concrete plan nine to twelve months in advance."[2] This policy was embodied in the Ministry contract[3] of 19 July, 1915, for 12,000 Vickers guns. Delivery of the guns was to be completed by June or August, 1916, the rate of delivery increasing steadily from 50 guns per week, at the beginning of the contract, to 634 by June, 1916. To meet the expense of extending the plant for increasing the rate of production, the Government agreed to give Messrs. Vickers financial assistance.[4] Orders for 6,000 Vickers guns were also placed through the firm in July, 1915, with the Colt Company of the United States of America.[5] In October, 1916, when Messrs. Vickers' contract for 12,000 guns was nearing completion, the Ministry entered into a further contract[6] with the firm for the supply of 5,000 guns; and in January, 1918, a contract[7] was made for the whole of their output.

By giving these large contracts, which assured to the manufacturers a certainty of a return on their capital outlay, the Ministry endeavoured to secure in addition to large supplies the greatest rapidity of output possible on the part of the firm.

(c) DEVELOPMENT OF THE FACTORIES AT CRAYFORD AND ERITH, 1915–1916.

Messrs. Vickers' factories at Erith and Crayford were the only source of supply for this gun until the last few months of the war. Thus, in 1915, it was essential to set up the new machinery with the greatest rapidity possible. To secure the increased output then required arrangements were made for setting up plant at Crayford to produce 400 guns per week, and for constructing at Erith a new shop to produce 100 guns a week and an extension of the works there to make 100 additional guns per week. The productive capacity of the two factories ultimately reached nearly 5,000 guns per month.

The greatest check on the extension of the factories was the serious difficulty of securing adequate skilled labour for setting up the machines. It was indeed to difficulty in securing such labour that the firm attributed

[1] HIST. REC./R/1000/119, p. 40.
[2] HIST. REC./R/1410/19.
[3] 94/G/367.
[4] See below, p. 21.
[5] 94/G/225.
[6] 94/G/4437.
[7] *Ibid.*

its failure to deliver to time. In this matter the Government gave every possible assistance to the firm. The Priority Committee,[1] in October, 1915, arranged that the skilled machine setters who were released from the Colours should be drafted to Crayford, as the most essential Government service. Still the numbers so secured were not adequate to provide the rapid installation of plant which was aimed at, and a scheme for using Italian labour did not materialise.[2] Within the factory attempts[3] were made to produce skilled labour by encouraging skilled workers to train others. A bonus of £1 was offered to machine setters for every learner who became proficient in machine setting under their instruction. As a result of these efforts the new plant at Erith and Crayford was installed by June, 1916; by the end of the year production had so far advanced that a contract for 2,000 guns for the French Army had been completed, and the capacity for manufacture for the British Government was therefore increased by nearly 100 guns per week.

The shortage of skilled labour which so severely checked the installation of the new machines was also felt in operating them, and attempts were made to secure skilled machine workers from various sources, particularly from the textile factories of Lancashire and Yorkshire.[4] Production up to the end of 1916 suffered not only from labour shortage but also from labour trouble, which seriously reduced output at Crayford in July and August.[5] A serious check on production was also the lack of co-operation between the factories at Crayford and Erith. Though both works were owned by Messrs. Vickers, and were within comparatively short distance of each other, they worked entirely independently. For instance, in December, 1915, machinery, for want of which production at Erith was being held up, was lying idle at Crayford.[6]

In spite of these difficulties considerable progress in production was made in 1916; both new shops were installed and set working, the French contract was completed and the weekly output was increased from 40 guns per week in January to 321 per week at the beginning of December.[7]

(*d*) Difficulties in 1917 and 1918.

Numerous minor difficulties prevented manufacture from proceeding smoothly after the manufacturing capacity had been extended. Early in 1917 output was jeopardised by a shortage of steel, and in September the same difficulty reappeared. In January, 1918, when there was a serious breakdown in the power station supplying Crayford, arrangements had to be made for supply from Woolwich. During 1917 progress was retarded for several weeks by the shortage of certain

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[1] (Printed) *Weekly Report* No. 14, II. (30/10/15).
[2] *Ibid.* No. 18, II. (27/11/15).
[3] *Ibid.* No. 19, II. (4/2/15).
[4] *Ibid.* No. 30, II. (19/2/16).
[5] D.D.G.E./E.M.1/365.
[6] D.D.G.(C)/C.M.G./181.
[7] (Printed) *Weekly Reports*, No. 23, II. (1/1/16); No. 71, V., (9/12/16).

components, which had not been foreseen by the firm.[1] Labour unrest also checked output from time to time, particularly during the engineers' strike of May, 1917.

(*e*) Establishment of a National Machine Gun Factory.

In August, 1917, the enormous demands of the new Air Force programme and the development of tank warfare made it clear that unless considerable extensions of production were secured[2] there would be a shortage of guns in 1918. Taking the most favourable estimate of the possibilities of output from Crayford and Erith and comparing the new scale of requirements with the expected output of Vickers guns in 1918, a deficiency was inevitable. A special committee was thereupon instructed by the Minister, in September, 1917, to consider and report on the question of the establishment of a National Machine Gun Factory in this country.[3] At a meeting on 11 September the possibilities of securing the needed increase through existing factories were seen to be small. The fact that both Crayford and Erith were in the day-raid area made any further extension inadvisable, even had such an extension seemed likely to produce greatly increased output.[4] A scheme for the immediate setting up of a National Machine Gun Factory was therefore formulated. It was estimated that the cost of setting up a factory to produce 400 Vickers air type guns a week would be about £750,000. Treasury sanction was received on 25 October, 1917. The site chosen was Burton-on-Trent, a place well outside the day air-raid area.

The greatest difficulty which was anticipated was the shortage of skilled labour; it was even thought that skilled labour for the new factory could only be found by transference of tool setters from some other type of munitions. By March, 1918, the building of the factory was proceeding satisfactorily, and most of the plant, tools and fixings were ordered. The system on which the new factory was to work was "the factory scheme," by which as many as possible of the components required for 10,000 guns should be ordered from such firms as were able to make them, and the components so procured should be the ones of which manufacture should begin last at the National Machine Gun Factory.[5] The factory was, however, still under construction at the close of hostilities, and the success of the experiment remained untested.

After the Armistice was signed the work of installing the new machinery was stopped, and the factory was employed in overhauling, repairing and skeletonising Vickers guns.[6] Early in 1919 the question of retaining a National Machine Gun Factory was under serious consideration. On the one hand, the expenditure on the factory had not had time to bear fruit, and the experiences of 1914–15 had shown the need for maintaining a nucleus of plant and of the highly skilled labour trained for this specialised class of work. On the other, a large stock of machine guns remained after the Armistice, the immediate need was

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[1] (Printed) *Weekly Reports*, No. 94, VII. (2/6/17).
[2] Hist. Rec./R/1122.8/1.
[3] *Ibid.*
[4] See below, p. 19.
[5] Hist. Rec./R/1410/12; D.D.G.E./E.M.8/9.
[6] Hist. Rec./R/1402/1.

for repair and upkeep rather than for manufacture, and the intention was to proceed with a standardised design of machine gun, for which the plant at Burton might not be suited. The factory was accordingly closed in May, 1919, and being retained for some time as a potential unit of supply, was ultimately sold for commercial purposes.[1]

III. The Supply of Lewis Guns.[2]

(a) EARLY CONTRACTS, 1914–1915.

Military authorities in 1914 were emphatic in their preference for the Vickers, rather than the Lewis gun;[3] but from the autumn of 1914 onwards, they accepted the need for using Lewis guns as a supplementary supply.[4]

Experimental guns were already being made for the Armes Automatiques Lewis by the Birmingham Small Arms Company, and ten guns had been purchased by the Admiralty and the War Office in July, 1914. At the same time, War Office instructions were issued that no guns should be sold except for the British forces. During August another 45 guns were ordered for the air service,[5] and in the first week of September contracts were placed for 200 more, for general service, to be delivered at 25 per week, from 15 October.[6] An additional 400 were ordered by the end of the year,[7] and delivered by May 1915; and another 400 ordered on 12 March 1915, were delivered in the following August.[8] In April a general request was given for preparations to manufacture 100 guns weekly, without any definite order being placed. In May, 1915, negotiations began for the production of 2,000 guns with extra spare parts,[9] and by 23 June an agreement had been reached for delivery of these guns from about 6 September at 100 weekly,[10] the time intervening between production on the two last War Office contracts being occupied in manufacture for the Admiralty.

There was considerable delay in reaching the rate of output first promised. It had been expected that the Birmingham Small Arms Company would be manufacturing 100 guns weekly by May, and 150 weekly by July, 1915.[11] During the nine weeks ending 12 June, deliveries to the War Office averaged only 36 per week. The delay was variously ascribed to difficulty in organising a properly synchronised production of the various parts, to the novelty of the weapon, to the extraordinary skill required from the operatives, to a general laxness of discipline amongst the labour employed and (as soon as the extensions were projected upon a large scale) to delays in obtaining machines.

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[1] HIST. REC./R/1402/1; D.D.G.E./E.M.8/475.

[2] The complex relations with the producers of these guns are given in greater detail in HIST. REC./H/1410/5.

[3] D.D.G.E./E.M.1/128.

[4] HIST. REC./R/1000/119.

[5] 77/6/4420.

[6] Contracts/G/1634.

[7] The formal contract was dated 11 February, 1915 (Contracts/G/1824).

[8] Contracts/G/ 2303.

[9] See below, p. 23.

[10] 94/G/195.

[11] R.S.C./G/151.

(b) Orders Placed by the Ministry, 1915–1918.

These same conditions continued to hamper expansion until the summer of 1916, in spite of the efforts which were made to increase output to meet the demands of the growing armies.

Immediately after control had passed to the Ministry, an investigation of the position showed that any increase in output was conditional upon the placing of larger orders, for the War Office and Admiralty had so far given definite contracts for under 2,000 guns, whilst the Government's action had prevented the firm from accepting foreign orders. It was proposed to purchase an additional 4,000 guns towards the increased machine gun programme,[1] but the Birmingham Small Arms Company was simultaneously engaging to effect a large extension for rifle output, and it became a question of deciding between the two projects.[2] On 29 June, 1915, the Minister agreed that the rifle extensions should be restricted in favour of machine guns. It was thus hoped that the weekly gun production would rise from 100 in July, 1915 to 300 in December, 1915, and 500 in March, 1916.[3] To the order for 2,000 guns already placed in June, 1915, there was accordingly added a contract for 10,000, which was formally executed in March, 1916. The capital advanced by the Ministry towards a certain proportion of the extensions was less than that promised towards the abandoned rifle plant, since the firm expected the post-war value of machine gun plant to be the greater of the two. The Birmingham Small Arms Company undertook to maintain the extended plant and machinery for twenty years in a condition to manufacture the Lewis machine gun at the rate of 500 per week at four months' notice, or a different model of gun at nine months' notice. Delivery of the 10,000 guns was to be complete by 31 May, 1916. Before this date a fresh agreement was negotiated whereby the output was to be extended to 750 weekly, and a running contract for the duration of the war was to be placed by the Ministry for this number, subject to four months' notice after 30 April, 1917. The Ministry again advanced a certain proportion of the capital expenditure upon extensions.

The contracts, so far, had been made with the Armes Automatiques Lewis, or with them and the Birmingham Small Arms Company, who were under agreement to manufacture the guns. From May, 1917, onwards, negotiations proceeded for a revision of the running contract in order to reduce the price, which was considered excessive in view of the large numbers of guns on order. The settlement of financial arrangements with the two companies presented a problem of great difficulty, and is dealt with below.[4] Meantime, the increasing demands necessitated a further development in the means of production. Eventually the Ministry entered into a direct contract with the Birmingham Small Arms Company for an increase in weekly output from the former 750 guns to 1,800, all of which would be taken by the Ministry. From 31 July, 1918, the company was to cease to carry out its former obligations to the Armes Automatiques Lewis, with

[1] D.D.G.E./E.M.1/128.
[2] 94/R/223.
[3] D.D.G.E./E.M.1/128.
[4] See below, p. 21.

whom the Ministry entered into a separate agreement.[1] This final contract with the Birmingham Small Arms Company was not formally executed until 10 December, 1918, and the four months' notice for its determination had already been given two months before. Output under the contract had reached 1,400 per week by August, 1918, and an average of 1,600 per week during the following October.

IV. The Supply of Hotchkiss Guns.[2]

(a) ESTABLISHMENT OF AN ENGLISH FACTORY, 1915.

The earliest arrangements for making the Hotchkiss gun in England were made in February, 1915, by the Admiralty, who then ordered 1,000 guns complete with spare parts from the Société Anonyme des Anciens Etablissements, Hotchkiss et Cie. Plant was brought over to Coventry from France, skilled workmen were released from the French Army, the French Government were to take half the guns from the Coventry factory until its output reached 100 monthly, and the disposal of any surplus output was to be the subject of agreement between France and Great Britain. The factory's output was expected to be from 25 to 50 guns a week. In September, 1915, the Admiralty exercised an option to purchase another 500 guns.[3]

(b) THE MINISTRY'S ARRANGEMENTS FOR EXTENDING OUTPUT.

Meantime, on 13 August, 1915, Mr. Lloyd George as Minister of Munitions sanctioned a scheme for doubling the factory's output, although British military authorities did not then accept this type of gun for service use.[4] The Ministry accordingly placed an order for 3,000 guns with the Société Hotchkiss in September, 1915, and the firm undertook to extend its works to produce a minimum of 100 guns weekly by March, 1916.[5] Ultimately, in March, 1916, the Ministry took over responsibility for the Admiralty contracts for 1,500 guns,[6] the first ten guns in respect of British orders having been produced by Christmas, 1915.[7] By the beginning of July, 1916, the factory delivered 1,013 guns, at a rate promising early completion of the demand for cavalry and tanks, which by that date had reached 1,700.[8] In the summer of 1916, it was anticipated that there would be a surplus output of guns over requirements from the following October onwards, and, while the military demand increased from time to time in July, August and September, output also developed, reaching 690 guns monthly by the end of October, and being expected to be 800 monthly by March, 1917. The abandonment of the Hotchkiss gun in favour of the Lewis gun for arming tanks in November, 1916, still further increased

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[1] See below, p. 22.
[2] For a more detailed account of this gun, see HIST. REC./H/1410/3.
[3] HIST. REC./R/1410/19; D.D.G.E./E.M.1/288.
[4] HIST. REC./R/1410/19.
[5] 94/G/529. The formal contract was dated 29 November, 1915.
[6] D.D.G.E./E.M.1/288.
[7] (Printed) *Weekly Report*, No. 22, II. (25/12/15).
[8] See above, p. 5.

the prospective surplus, so that at the end of 1916, the total British demand was likely to be met by the end of February, 1917. The War Office accordingly suggested that manufacture of this type of gun should cease.[1] It was, however, considered desirable to maintain the factory as an insurance against any accident to the Birmingham factory for Lewis guns. A further contract was accordingly placed with the Société Hotchkiss on 1 February, 1917, with the intention of providing guns for the Allies. Under this contract, the Minister agreed to take the output of the factory and 4,500 guns after giving notice of termination, the minimum weekly output to be 200 guns.[2] Deliveries were diverted almost immediately to the British forces since 2,000 additional Hotchkiss guns were required by the War Office in March, 1917, and early in May, 1917, this type of gun was again adopted as the armament for tanks.

(c) The Maintenance of Production, 1917–1918.

Thenceforward the maximum output of the factory was maintained to meet steady increases in the demand for tank armament and for anti-aircraft purposes, and by the end of the year a stock of 4,000 guns had been accumulated. Early in 1918, with the increased requirement for tanks, various projects were put forward for extending the factory or adding larger works on an adjacent site; but certain comparatively small extensions which were effected by the firm eventually sufficed to bring output up to an average of 500 guns per week during the month preceding the Armistice,[3] and, with the aid of the stock already built up and of salved guns, to meet the demand, except for the armament of Inter-Allied tanks. A modification of the cancellation clauses of the contract was then under discussion, and in December, 1918, it was agreed that a maximum of 10,000 guns were to be delivered from the date of notice, and that any number of these might be cancelled on payment for work actually done. It was accordingly arranged that work should cease in March, 1919.[4]

V. Attempts to provide the Madsen Gun.[5]

(a) Orders from Copenhagen.

The representative of the Dansk Rekylriffel Syndikat, owners of the Madsen gun patents, approached British naval and military authorities for orders in April, 1915, offering to manufacture 200 guns in Copenhagen between 15 June and 15 August, and 50 a month for the following three months, with a subsequent increase to 150 a month. In spite of the difficulty of obtaining delivery from Denmark, the Admiralty ordered 400 guns for the marine service and for aircraft service on 10 May, 1915, refusing to take any deliveries later than December, 1915. Upon the execution of the contract, 50 per cent. of the cost was to be paid, 25 per cent. on receipt of bills of lading,

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[1] D.M.R.S. 135 M2.
[2] 94/G/4946.
[3] D.D.G.E./E.M.1/836.
[4] S.A.M.G. 57.
[5] For the detailed account of negotiations in regard to this gun, see Hist. Rec./H/1410/1.

the remainder when the guns reached England in a satisfactory condition. The War Office at first rejected the offer; but upon receiving Sir John French's request for the provision of these guns,[1] they ordered 500, 25 of which were to be equipped for cavalry service and the rest for infantry. Delivery was to be complete by the end of February, 1916.

In June, 1915, Mr. Moir investigated the possibility of increasing the supplies from this source. The Syndicate had then no difficulty in obtaining the necessary material from Sweden, but the difficulty of obtaining deliveries from Denmark seemed insuperable. Attempts to obtain the guns through neutral states failed, chiefly because the states with whom the arrangements were being made ceased to be neutral before the transaction was effected. The date for completing the British orders was deferred to May, 1916, and manufacture was not actually completed until the following November. The Ministry, which had taken over both the naval and the military contracts, ceased early in 1916 to regard their fulfilment as a practical question. Existing sources of supply then promised a surplus of other types of machine gun towards the end of the year, and in January, 1916, the Army Council had definitely rejected the Madsen gun in view of the organised supply of other types.[2] Formal delivery of the 900 guns was made in Copenhagen late in December, 1916, and payment of the 25 per cent. due at this stage was made in the following April, the guns having first been stored under British control and verified as guns of British pattern. The difficulty of export remained unsolved until the end of the war.

(b) Projects for an English Factory.

The alternative of transferring the Danish factory to England was considered during the summer of 1915; but the Syndicate was unwilling to remove its factory or part with any of its plant. Meantime, Messrs. Rolls-Royce, who in the first month of the war had offered to make machine guns, undertook to establish a factory for making the Madsen gun from a sample, with financial assistance from the Ministry and technical advice from the Syndicate. In July, 1915, their representative signed a provisional agreement with the Syndicate, and eventually it was agreed between the two companies that Messrs. Rolls-Royce should be sole makers of the gun in the British Empire, and should erect a factory for 200 guns or more monthly; while the Syndicate undertook to supply a model gun, full drawings of the gun and tools, and four experts. Messrs. Rolls-Royce were to divide their profits with the Syndicate, the minimum price per gun being fixed at £100, save that Messrs. Rolls-Royce might sell to the British Government at £85 per gun after the sale of 5,000. By a draft agreement, dated 6 September, 1915, the Ministry was to place an order for 5,000 guns with Messrs. Rolls-Royce at £100 each, providing working capital up to the date when first deliveries were due, and advancing 75 per cent. and paying 25 per cent. of the capital expenditure upon constructing

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[1] See above, p. 3.

[2] See above, p. 3.

a factory for 100 guns weekly, the tool room to be equipped by 1 November and the big shop by 1 December, 1915, and manufacture to begin by 1 April, 1916. A supplementary arrangement was also made for the equipment of an existing factory pending the erection of the new premises.

From the outset the progress of the scheme was exceedingly slow. The first drawings were despatched from Copenhagen on 12 October; the model gun was not sent until 20 October, and was delayed because the vessel carrying it ran aground. By 18 December all the important drawings of the gun had been received, but the drawings for tools, jigs and gauges were further delayed, and when they did arrive they proved to be inaccurate. With the rejection of this gun in January, and the improved position in regard to machine guns generally, the project was formally abandoned in March, 1916, mainly by reason of the unsatisfactory information and drawings which had been furnished. There were other causes contributing also to its ill-success. Constructional steel and machine tools were delayed, and the supply of labour lagged behind the provision of tools. Although one-half of the machines had been installed by Christmas, 1915, only about 20 men were engaged upon the work. In January, 33 per cent. of the machines installed (65 per cent. of the complete equipment) were at work. The contract, which had never been formally executed, was formally cancelled on 10 April, 1916, and two years later the Danish Syndicate accepted Messrs. Rolls-Royce's repudiation of the agreement between the two firms.

After the Government's decision to make use of the gun in January, 1918, a renewed attempt was made to secure the transfer of the Danish factory to England. The Syndicate, whose financial position had suffered during 1917 through difficulties in the transmission of drafts from a company which it had established in Russia, was prepared to part with its plant and staff and its patent rights within the British Empire; but the negotiations which followed failed to produce satisfactory financial terms, and the scheme was definitely abandoned when the Army Council pronounced against the use of this gun in April, 1918.

CHAPTER III.

GENERAL METHODS OF SUPPLY.

I. The Sources of Supply.

When war broke out, the only British factories for making machine guns were the works of one armament firm (Messrs. Vickers), which were capable of producing 10–12 guns of the latest pattern a week, and the machine gun shop at the Royal Small Arms Factory, Enfield, which was chiefly engaged in operations concerned with repair and conversion and with the manufacture of the obsolescent Maxim gun. Practically the whole of the capacity of the Royal Small Arms Factory was needed for rifle manufacture. The Factory's output of complete Maxims during the first 18 months of war was just over 50. In the autumn of 1917 it ceased making any complete guns, at the same time increasing its output of spare parts for Vickers guns and undertaking the repair of salved Vickers guns. With this exception, supplies were entirely drawn from contractors until the end of the war, for the single project for establishing a national machine gun factory at Burton-on-Trent had not materialised at the date of the Armistice.

Messrs. Vickers extended their works for making their machine guns until, at the close of the war, they were able to produce nearly 5,000 a month in two factories, the one at Crayford and the other at Erith, both within the district specially exposed to daylight air raids.[1] In the autumn of 1914 the military policy of providing this type of gun only was so far modified as to admit supplementary supplies of a second proprietary type, the Lewis machine gun, of which the European patent rights were owned by a Belgian company. The guns were produced for this company by a well-established British firm of rifle makers, who were manufacturing them at Birmingham on an experimental basis at the outbreak of war, and contrived by the end of the war to build up an output of 1,600 per week, their total output far exceeding that of the Vickers factories. This important source of supply was partly established at the cost of reducing rifle production.[2] To these two sources a third was added by the Admiralty early in 1915, by encouraging the proprietors of a French machine gun (the Hotchkiss) to erect works at Coventry. This factory, originally intended for an output of between 25 and 50 weekly, was eventually extended to produce 500 weekly during the last few months of the war, this type of gun having been adopted early in 1916 for special purposes, viz., for cavalry and tanks.[3] Thus at the end of the war, the country's manufacturing capacity consisted of three trade ventures, which were together able to make over 3,000 machine guns a week. The three makers were all accustomed to machine gun or rifle manufacture, and they alone produced complete guns, although large numbers of components were produced by miscellaneous firms.

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[1] See above, p. 10. [2] See above, p. 14. [3] See above p. 15.

The single attempt to introduce an outside firm to machine gun manufacture was a conspicuous failure, partly by reason of difficulty in obtaining information as to the gun to be made (the Madsen) from its Danish proprietors.[1]

Overseas purchases of machine guns were strictly limited. It proved impracticable to secure the export of Madsen guns from Denmark, even when delivery had been accepted in Copenhagen.[2] The American supplies available early in 1915 were all for late delivery,[3] and although orders were placed by the War Office for Vickers guns to be made by the Colt Company and delivered from October, 1915, onwards,[4] American capacity was mainly left to the Allies. Thus, for example, an American contract for Lewis guns placed in December, 1915, was afterwards transferred to the Russian Government.[5] Again, in 1917, it was considered that the whole of the capacity of the United States was needed for equipping the American armies. At that time, also, exchange difficulties and the risk of losses at sea prevented the placing of orders for complete machine guns in Canada. Even if French supplies had been available they would have been undesirable, because of difficulties in inspection and, hence, in interchangeability.

The production of the Lewis and Hotchkiss guns did not suffice to break the monopoly in the Vickers gun, whose makers failed from the first to redeem their promises as to delivery and were still in arrear in the summer of 1917.[6] The extremely restricted basis of supply resulted in correspondingly high prices.[7] Without a Government factory, the Department found it difficult to obtain satisfactory knowledge of costs upon which to base financial negotiations. When in August, 1917, demands for Vickers machine guns increased beyond the facilities for extending the existing factories, the opportunity was accordingly taken to establish a national factory for 400 aero-type Vickers guns per week. The new factory was intended to be the central assembling shops of a scheme for component production by various firms capable of making individual parts but not the whole gun, so as to reach production rapidly. Eventually complete guns were to have been produced at the factory itself. The Armistice was signed before the scheme had materialised, so that its results remained untested;[8] but investigations whilst the work was being liquidated showed that the progress had been most promising.

In 1917, the rate of repair of machine guns became of considerable importance. Whilst this work had been the duty of the inspection authority, whose space and staff for the purpose was strictly limited, it was necessarily put aside in favour of the inspection of new guns, and considerable numbers of repairable guns had accumulated. With the transfer of this duty to the supply authority in 1917, it was undertaken by the Royal Small Arms Factory, where repair soon reached the rate of 50 per week, and afterwards increased.[9] At the time of the

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[1] See above, p. 18.
[2] See above, p. 17.
[3] Hist. Rec./R/1000/119, p. 40.
[4] 94/G/225.
[5] R.S.C./G/20; D.D.G.E./E.M.1/321, 392.
[6] Hist.Rec./H/500/10, p. 15.
[7] See below, p. 21.
[8] See above, p. 12.
[9] M.C. 33.

British retirement in March, 1918, a promise was made to the Minister of 400 repaired guns a week, so long as salved guns were available, and this promise was fulfilled.

II. Relations with Contractors.

(*a*) FINANCE.

The prices for all three types of gun were high, and the reductions eventually made were the result of hard bargaining. The first comparatively small orders placed with Messrs. Vickers in August and September, 1914, were at prices ranging from £167 to £162 per gun (inclusive of spares). On the larger orders of September, 1914, the firm refused to make any reduction on the ground that the consequent reductions in manufacturing costs were balanced by the need for providing capital for the extensions. The price subsequently fixed for the large orders placed by the Ministry in July, 1915, was £125 per gun, a rebate of £25 per gun being made towards the £300,000 advanced by the State towards the new factories. In 1916 the price was fixed at £100. The running contract placed in January, 1918, included a scheme for prices to decrease, as increasing numbers were supplied, from £100 to £80, or to £72 10*s*. for the ground and air-type of gun respectively. Further negotiations in May, 1918, provided for a reduction to £74, or £66 15*s*. on a cost basis.[1] It had been calculated in July 1917, that the cost of production could not be more than £50 per gun.[2]

Financial relations with the makers of the Lewis gun (the Birmingham Small Arms Company), were complicated by the claim of the patent holders (Armes Automatiques Lewis), to exemption from taxation, and by the terms of an agreement between the two companies.[3] The experimental guns purchased in July and August, 1914, cost £175 or £165 each, according to whether the mounting was included. The same price was paid on the larger orders placed by the War Office. In May, 1915, a reduction was refused by the patent holders on grounds similar to those advanced by Messrs. Vickers in the previous September. The price fixed on the first Ministry order for 10,000 guns was £135, a rebate of £35 per gun being allowed in consideration of the £275,000 advanced toward the machine gun extensions at Birmingham. A reduction to £85 and £80 per gun was effected in placing the running contract of 1916; even the reduced price was considered exorbitant in view of the projected increases in manufacture, and lengthy negotiations were undertaken with a view to its further reduction or the negotiation of an entirely new contract. These negotiations broke down over the claims of the patent holders to be exempt from British taxation. A project for special legislation to empower the Ministry to revise contracts which had become inequitable because of increased production and reduced cost was put forward and abandoned. The Department thereupon fell back upon its power to investigate the cost of manufacture of any munition work. It was proved in July, 1918, that the cost of producing a Lewis gun was then considerably less than

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[1] For details of these reductions, see HIST. REC./H/1410/2.

[2] HIST. REC./H/500/10., p. 15.

[3] See below, p. 23.

£30, *i.e.*, out of the £80 paid per gun, £50 went straight to the two companies. On the basis of this knowledge a fresh contract was drawn up directly with the Birmingham Small Arms Company, thus avoiding the difficulties arising from the question of the patent holders' claims to be exempt from taxation. The price agreed upon the basis of the largely increased output in July, 1918, was £25 for ground guns and £24 10s. for air service guns. At the same time the Ministry arranged to buy out the Armes Automatiques Lewis on terms which effected a very considerable saving should the war last till August, 1919, and a slight saving otherwise. An agreement to this effect was executed shortly after the Armistice; but the question of the company's liability to taxation then remained unsettled.[1]

The first price for Hotchkiss guns arranged by the Admiralty in February, 1915, was £175 each, a reduction being anticipated in the event of further orders. When the first contract for 1,000 guns was increased to 1,500, the agreed price was accordingly reduced to £150. The Admiralty also made considerable advances towards the establishment of the Coventry factory. Under the first Ministry contract, £45,000 was contributed towards new buildings and plant, and the price fixed for 3,000 guns was £110 each. In May, 1916, the Ministry advanced £15,000 for plant to manufacture additional numbers of spare barrels, the loan being repayable at 15 per cent. of the value of the barrels supplied. When the order for 4,500 guns was placed in February, 1917, the price was fixed at £100 per gun; but the actual number of guns to be delivered under this contract, between February, 1917, and November, 1918, was eventually 26,000. In consequence, a revision of price was called for in April, 1918, when the Department suggested an adjustment by means of cost investigation. The company strongly resisted this suggestion, but agreed later to a partial investigation, in view of further increases in their orders. As a result, the price from 3 July, 1918, onwards was settled at £55 per gun. The question of reducing prices on the earlier contracts, in view of the large profits obtained, was still under consideration when hostilities ceased, and was closely connected with the company's claims to be exempt from taxation.[2]

In dealing with both of the foreign patent holders, Armes Automatiques Lewis and the Société Hotchkiss, the Ministry had refrained in 1915 from declaring the companies controlled establishments under the Munitions of War Act. Since the Belgian company had no factory in England, they had been definitely informed that they could not be controlled under the Munitions of War Act, nor come under the munitions levy. Both companies insisted upon their claim to be exempt from British taxation, and the settlement of this claim grew in importance with the imposition of the excess profits duty and the rapid development in the quantities of guns ordered. It was brought to a crisis when the costing investigations of 1918 revealed the enormous amount of the profits which the companies had been making. It was, for instance, estimated that the profits of the Armes Automatiques

[1] HIST. REC./H/1410/5.

[2] HIST. REC./H/1410/3, pp. 21–25.

Lewis (apart from those of the Birmingham Small Arms Company), had amounted between March, 1915, and March, 1918, to £4,624,937, upon which excess profits duty would have amounted to £3,304,852, and income tax to another £329,907.[1] The settlement of the claims of both these companies to be exempt from taxation was still outstanding at the date of the Armistice.

(*b*) THE PROVISION OF SPARE PARTS.

Reliance was at first placed upon the scheduled spare parts provided under contract with each complete gun, to replace those components which were most subject to wear or casualty. The nature of the set of spares thus provided varied with the different guns. The lighter guns were particularly subject to casualty.

Satisfactory supplies depended upon the organisation of the makers' factories for synchronising the production of numerous components. The Vickers gun, for instance, consisted of over 400 different parts which were not permanently assembled together. Certain spare parts should also have come forward with each gun, but the number of the spare parts demanded was frequently changed as a result of experience in the field. Thus, instead of the one spare barrel and 12 magazines at first provided with each Lewis gun, 3 barrels and 80 (modified later to 52) magazines were required in May, 1915. The supply of these extra spares threatened to reduce seriously the output of complete guns, even though the Birmingham Small Arms Company had financed a firm of cycle makers to make the extra magazines. In the emergencies of 1915, Lewis guns went forward without the provision of the full quantity of spares, and as a result, when guns in France went out of action, there was no means of replacing the broken parts except by taking spare parts from guns in the course of manufacture. In November, 1915, arrangements were revised, so that two barrels were provided with each of these guns and a large number of spare barrels for upkeep was ordered separately. Similarly, a separate running contract for magazines was placed with the Armes Automatiques Lewis, in February, 1916.[2] Similar difficulties were experienced in organising the provision of spare parts for Vickers guns ; and in July, 1916, the output of complete guns was stopped temporarily, in order to bring up the arrears of spare parts.[3] A separate contract for spare barrels was also placed with Messrs. Vickers in February, 1917, and a system of obtaining spare parts from other contractors and also from the Royal Small Arms Factory was being gradually extended during the year 1917.[4] In June, 1917, when machine gun supply had been placed upon a sound basis, the contracts for complete Vickers and Lewis guns again included the full requirement of spare barrels. At the same time the supreme importance of maintaining the guns already in the field was reflected in a clause enabling the Ministry to give orders for new Lewis guns to be broken up with a view to securing deliveries of spare parts.[5]

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[1] M.C. 713.
[2] HIST. REC./H/1410/5.
[3] HIST. REC./R/1410/20.
[4] M.C. 33.
[5] HIST. REC./H/1410/5.

The factory system, which was centred round the National Machine Gun Factory at Burton, provided for the manufacture of certain parts by various engineering firms. It was thus intended to provide a "pool" of components for machine gun manufacture similar to the rifle component pool which was already in existence.[1]

III. Labour.

The manufacture of machine guns needs an exceptionally high proportion of skilled labour, not only for the hand-work involved, but also as tool and gauge makers. Difficulty in obtaining machine-setters to install new plant and the operatives to work it was also among the causes for delays in obtaining immediate output during 1914 and 1915. At Crayford the former problem was overcome by a bonus on training, and the latter by drawing skilled men from the textile industry.[2] At Birmingham lack of skill among the operatives was assigned as a reason for the poor quality of certain parts in 1915; but the Birmingham Small Arms Company experienced, on the whole, little difficulty in obtaining operatives.[3] Dilution was particularly difficult to enforce in the factory of the Société Hotchkiss, since this was not a controlled establishment under the Munitions of War Act. Until January, 1917, the company successfully opposed any effort to introduce female labour. They then agreed that, provided their works remained uncontrolled, they would follow the Minister's directions in introducing a percentage of women operatives and would submit changes in rates of wages for Ministerial approval. A considerable number of female operatives was introduced in 1917; but dilution was strongly opposed by the workers, and in February, 1918, there were still 100 highly-skilled men doing semi-skilled work in the Coventry factory at high rates of pay.[4]

The provision of skilled labour was one of the chief problems in establishing the national factory for machine gun manufacture in 1917-1918. It was at first considered that when the factory was in working order the skilled operatives could only be obtained by withdrawing men from other munition work;[5] but up to the point reached at the Armistice the necessary skilled labour had been obtained or trained without seriously depleting other factories.

IV. Inspection.

One of the main problems in regard to inspecting machine guns was to secure interchangeability of parts. It was partly the difficulty in organising inspection for this purpose that prevented the purchase of machine guns from overseas.

At home, inspection took place at contractors' works. Vickers guns were gauged and tested both at Crayford and Erith until September, 1917, when inspection was concentrated at Crayford

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[1] See Vol. XI., Part IV., p. 20; see above, p. 12.
[2] See above, p. 11.
[3] Hist. Rec./H/1410/5, pp. 19–22.
[4] Hist. Rec./H/1410/3, pp., 26–29.
[5] Hist. Rec./R/1122/66.

as a matter of convenience, and in order to ensure uniformity of standard. The guns were tested for accuracy at a neighbouring range at Slades Green. Similarly, Lewis guns were inspected and shot for accuracy at Birmingham; and Hotchkiss guns made at Coventry were inspected there, and sent to a range at Radford near by for functioning and accuracy tests.[1]

V. Summary of Output.[2]

At the outbreak of war the Vickers machine guns were superseding the obsolescent Maxim, and 106 of them had already been delivered to the War Office. The pre-war stock of the two guns was 1,955. By the end of 1914 the orders placed by the War Office since the outbreak of war had produced 266 more Vickers guns, besides eight of the Lewis guns which had been ordered for aircraft, and as a supplementary supply in August-September, 1914, and 13 Maxims, which were produced by the Royal Small Arms Factory. The total number of machine guns ordered by the War Office between August, 1914, and May, 1915 (inclusive), was 3,344—namely, 1,792 Vickers, 1,052 Lewis and 500 Madsen guns. Promises had been made for the delivery of 2,482 of these (namely, 1,592 Vickers and 890 Lewis guns) by 29 May; but the actual acceptances up to that date were 775 Vickers and 264 Lewis, making a total of only 1,039.[3] The actual number of machine guns in service when the Ministry of Munitions became responsible for supply was 1,330, inclusive of Maxims. There were on 1 June, 1915, more than the number required to equip the Army on the old scale of two machine guns per battalion, but only sufficient to provide 12 out of the 30 divisions then waiting to be equipped on the new standard of eight per battalion.[4] The immediate shortage was mainly due to the failure of either Messrs. Vickers or the Armes Automatiques Lewis to redeem their promises as to immediate delivery.[5]

So far, orders had been placed continuously in accordance with the estimated capacity of the machine gun makers. On 9 June, 1915, the total orders so placed were for 7,344 machine guns, delivery of which ran as late as December. In order to increase production up to the 13,220 guns then required by March, 1916, the Ministry gave financial assistance towards large extensions for Vickers and Lewis gun manufacture, placing orders for a considerable number above the requirement as a means of encouraging contractors to hasten deliveries. Similarly, in August, 1915, an order was placed for Hotchkiss guns in anticipation of the formal military demand, and an attempt was made to establish a Madsen gun factory in England to produce a surplus of guns over the requirement as it then stood.[6] It was anticipated in September, 1915, that the supply of machine guns under these arrangements would overtake requirements on the scale of eight guns per battalion by April or May, 1916, and that a surplus of over 47,000 would become available by the summer of 1917 either for the Allies or for the British forces in case their requirements should increase.

[1] M.C.33.
[2] Hist. Rec./H/1410/4.
[3] Hist. Rec./H/1410·1/1.
[4] Hist. Rec./R/1410/3.
[5] See above, pp. 10, 13.
[6] Hist. Rec./H/1410/1, p. 29.

The Minister (Mr. Lloyd George) was not satisfied that even these surpluses would suffice to meet the ultimate needs of the British Army, and on 24 September, 1915, he authorised a 50 per cent. increase of production for the six months beginning 1 March, 1916.[1] These orders were to be on the British account, and not guns of Russian or Belgian calibre. They were justified by the doubling of the standard of equipment in the following month and by the continuous increase in British requirements until October, 1916.[2] The greater part of the surplus capacity was thus absorbed by British needs; although the total number of machine guns supplied by Great Britain to her Allies by the end of 1916 was over 2,900, irrespective of some 5,600 purchased by Great Britain for Russia in the United States of America.[3]

In November, 1916, arrangements were made for the three British contractors to work up to their full capacity, provided that they did not increase the number of their employees eligible for military service. It was expected thus to create a reserve, either for Allied or British use, and to reduce the costs of manufacture. During the winter of 1916–1917, the rate of production was accordingly working up to 1,300 per week (450 Vickers, 650 Lewis and 200 Hotchkiss). Considerable numbers thus became available for the Allies, to whom over 11,000 machine guns of British manufacture were supplied during 1917, nearly 7,000 Vickers and Lewis guns being taken by France.[4]

The increased demands from August, 1917,[5] onwards, were again met by extensions to the capacity of the existing firms and by the project for the national factory, which was intended to redress an adverse balance in the output of Vickers guns. The total output of Vickers, Lewis and Hotchkiss guns during 1917 had been over 79,700; during 1918 it was 120,800, and plans were made for the manufacture of over 192,000 machine guns during 1919.

The rate of production had thus been vastly increased during the war. The original maker of the only type of gun accepted at the outbreak of war was producing about 12 machine guns a week in August, 1914; and by November, 1918, was delivering about 1,000 a week. The largest of the new concerns, the Birmingham factory for Lewis guns, had been built up *ab initio*, and was producing 1,000 a week in November, 1918. The lesser undertaking which had been created for providing Hotchkiss guns was delivering 500 per week in November, 1918. The actual capacity of the country in November, 1918, was in excess of the current rate. The Vickers factories could have produced 1,200 guns weekly, and the Lewis gun factory 2,000. These figures, together with the 500 Hotchkiss guns weekly, and the possibility of repair at the rate of 400 salved guns, if these were available, brought the country's total capacity for machine gun output up to 4,100 per week. In 1919 this would have been further increased by the productive capacity of the National Machine Gun Factory.

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[1] D.D.G.E./E.M.1/193.
[2] See above, p. 5.
[3] Hist. Rec./H/1010/3.
[4] *Ibid.*
[5] See above, p. 6.

OUTPUT OF MACHINE GUNS.

August 1914—December 1918.[1]

Type	1914, Aug.-Dec.	1915	1916	1917	1918	Total	Percentage of total output.
Maxim	13	38	307	308	Nil.	666	·3
Vickers	266	2,405	7,429	21,782	39,473	71,355	29·7
Lewis	8	3,650	21,615	45,528	62,303	133,104	55·3
Hotchkiss	Nil.	9	4,156	12,128	19,088	35,381	14·7
Total ..	287	6,102	33,507	79,746	120,864	240,506	100·0

The preceding table shows the actual deliveries of each type of gun year by year. Manufacture of Maxim guns continued on a comparatively small scale until 1917. The output of the Vickers gun represents about 30 per cent. of the whole number supplied, while the Lewis gun deliveries account for more than 55 per cent. The Hotchkiss gun did not come forward until late in 1915 and was never required in such large numbers as the Vickers or the Lewis. Accordingly, it accounts for less than 15 per cent. of the total. In all, more than 26,900 machine guns of British manufacture were supplied to the Allies, out of a total of over 240,500 manufactured during the war.

[1] Figures denote issues of Maxim guns from Enfield (HIST. REC./H/1122·1/4), and acceptances of other types from contractors (*Review of Munitions Output. 1914–1918*, p. 68).

VOLUME XI

THE SUPPLY OF MUNITIONS

PART VI

SMALL ARMS AMMUNITION

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CHAPTER I.

INTRODUCTORY.

The war witnessed the invention and development of many new weapons, both offensive and defensive. Yet, highly mechanical as modern warfare has become, the human element has not been eliminated, and in the last resort the soldier with his rifle is still the decisive factor. In organising the supply of munitions small arms were no less important than guns, shells, aircraft, tanks and the many other weapons of war which attracted the notice of the civilian, rather because of their size or their novelty than because of any intrinsic claim to priority. In one way the supply of ammunition forms a part of the small arms problem, in another it stands by itself; for though the rifle and the machine gun are inseparably connected in action with the cartridge, the problems of manufacture and supply are by no means the same.[1]

The problems which faced the War Office and the Ministry during the four years of war will be discussed in the following chapters. Broadly, however, they may be indicated here, for among the minutiæ of supply, the general trend of policy and the principles guiding activity are apt to be obscured. Prominent among the factors conditioning supply was the necessity for keeping large stocks of ammunition in hand. A plentiful supply of cartridges had always to be in the very front line; in any sudden reverse or long drawn out retreat the losses were therefore abnormally heavy. Expenditure similarly took place at an accelerated rate either in defensive operations or in big offensive movements, and this expenditure was still further increased by the development of the machine gun barrage. Lastly, the *morale* of the soldier depends largely on his faith in his rifle: for this reason, also, plentiful supplies were essential. In calculating supply, it was always therefore necessary to hold a large reserve of ammunition to meet a sudden emergency. This is reflected in the anxiety of the War Office whenever the reserve grew low, and is proved by the events of March and April, 1918. For the War Office, the question after June, 1915, resolved itself merely into a matter of stating requirements and seeing that they were met; for the Ministry the issue was not nearly so simple, and there were periods when the views of the War Office and the Ministry as to the amount of output were by no means identical. To build up a large stock and to meet large requirements there were comparatively few sources of supply. The small arms ammunition industry

[1] When the Ministry of Munitions was established in June, 1915, although the supply of small arms and of small arms ammunition was the responsibility of the same Deputy Director-General (C), a separate section of his department dealt with the question of small arms ammunition. In January, 1916, this section became part of a new Deputy Director-General (E)'s department, and under the direction of Mr. Alexander Duckham was known as E.M.$_2$; in August, 1917, it became an independent department under Mr. L. Gordon, who acted as controller until the work of supply and liquidation was completed.

is a highly technical one, requiring special knowledge, special skill and plant which is not easily convertible to other uses. Hence it is confined to a few firms, whose output, though sufficient to meet the demands hitherto experienced, proved entirely ineffective to cope with the large scale requirements of 1914. Before the Ministry took over supply, the War Office was faced with the problem of how to deal with the emergency, but it was left for the Ministry to decide between the alternative policies of expanding the output of existing firms or introducing new firms into the industry. The decision was closely bound up with the conditions in the machinery trade, the supply of labour and the paramount importance of accurate and fine workmanship, and it was in the face of extraordinary difficulties in all these directions that the Ministry had to meet the demands upon it, and build up the increased organisation for supply.

The problem of supplying standard ·303 in. Mark VII ammunition in bulk was difficult enough: it was complicated by the demands of our Allies for assistance—demands which generally involved the manufacture of special calibres—and by the demands for special types of ·303 in. ammunition which began to pour in as aerial warfare developed. Tracer and incendiary ammunition was in its infancy in 1914; armour-piercing ammunition, though a stage further advanced, was still far from fulfilling its functions adequately. Hence the design of these types had to go on side by side with supply; consecutive stages in the development of a store had to be taken *pari passu;* and during 1916 and 1917 it was usual for batches of an imperfectly designed store to be manufactured for use while the staffs of the Royal Laboratory and of the big trade firms were indefatigably experimenting on a better design. All this added immensely to the difficulties and costs of production; attention was distracted from normal production, delays and disappointments were inevitable. If 1915 was the critical period for production in bulk, 1916 and 1917 were the searching test of our inventive powers and of our practical capacity to overcome difficulties. 1918 saw us in smoother waters, and supply, both in bulk and in variety, proceeding with comparative ease.

Thirdly, there was the question of finance. In the chaotic industrial conditions resulting from war, all the ordinary mechanism of contract collapsed. Hence the Ministry had to evolve new financial arrangements as well as producing unexpected quantities and entirely novel designs. On account of the peculiar circumstances of the industry the financial expedients adopted were varied and ingenious. In the early days they practically amounted to individual settlements with each firm. As the result of experience these gradually merged into the basis price and sliding scale system, a compromise between the old free contract method and the new system of price control which was developed as a general principle by the Ministry. Apart from its practical value at the time, the basis price and sliding scale system, with its corollary, the investigation of firms' accounts, has provided a great deal of evidence in support of the principles of scientific management.

All these questions of supply, design, and finance were already straining the organisation of the War Office Contracts Department when the Ministry took over the supply of munitions. Though the War Office had made tentative efforts to find solutions, it was left for the Ministry to grapple with them firmly: its efforts and its achievements form the history of supply.

The record from 1915 to 1918 is one of never-ceasing effort. Whatever may have been the mistakes, this salient fact stands out as one surveys the history of those three and a half years; the supply of ammunition never once failed the troops at the front. For this achievement full credit must be given to the workpeople in the factories and to the directors and managers of the supplying firms. But over and above this there was the organisation from the centre, without which all the effort of individuals and small groups would have been largely wasted.

It should be noted that the following chapters are based principally upon the records of the department responsible for the supervision of production (Supply Department) and does not fully reflect the work of the Design and Inspection authorities.

CHAPTER II.

DEVELOPMENTS IN DESIGN.

The history of small arms ammunition manufacture before and during the war illustrates clearly the necessity for the supply departments being always prepared to meet new demands arising from such requirements as may become manifest for the first time or may assume greater importance during the progress of operations. This can only be secured if every technical and manufacturing possibility in connection with the weapons is fully investigated; not merely to meet immediate needs, but to determine the lines of progress in directions where the immediate need is less obvious.

The absence of any such complete research and of any provision for experimental manufacture apart from output in quantity made it necessary to carry on the work of design and research simultaneously with manufacture. This involved the temporary adoption of inferior designs whilst manufacturing facilities were being developed, and it was a source of continual anxiety as to how far experimental work could be carried on without interfering with output, at a time when all the skilled supervision available in private and Government factories was barely sufficient for the extensions necessary to meet ordinary requirements.

At the beginning of the war only two designs of ·303 in. ammunition were being manufactured, ·303 in. Mark VI, the round-nosed type, practically obsolete as far as the home army was concerned, but still required by the Admiralty and the colonies, and ·303 in. Mark VII, the pointed type, the core of which was in two parts, an aluminium tip and a lead main core. This latter design had not been long adopted and involved extra processes in manufacture which considerably affected output. In addition to these designs investigations had been made into a design for a tracer bullet for the air services, and a few had been made experimentally. The Roth design of armour-piercing bullet (that adopted in Germany) was known, but no experience had been obtained in the manufacture of its components.[1]

I. Armour-piercing Ammunition.

The demand for armour-piercing ammunition proved throughout one of the most difficult to meet. Up to the end of 1917 it was used principally by snipers against loopholed plates, machine gun shields, and body armour, and the demand apparently arose from the success of the German armour-piercing bullet against such targets. The merit of the Roth design was realised from the first, but it was not possible to obtain suitable components at once. As a temporary measure, therefore, the Royal Laboratory undertook the manufacture of a bullet resembling the Mark VII but with a steel tip instead of an aluminium

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[1] Hist. Rec./H/1440/4.

one. This was introduced into the service as Mark VII S. In penetrative qualities, however, it proved unsatisfactory, so at the end of 1915 all British makers were invited to produce designs and samples of armour-piercing bullets, the intention being to obtain the best design possible, and also to accept bullets of any other efficient design that makers could produce.[1] The urgent necessity for improving the R.L. type, the ·303 in. Mark VII, was brought home to the War Office by a series of reports forwarded from G.H.Q., France, in March, 1916. Trials made by corps belonging to the First, Second and Third Armies and by the Machine Gun School at G.H.Q., showed that the bullets failed to penetrate even at comparatively short ranges. The Commandant of the Machine Gun School thought that better results would be obtained if bullets for larger calibre rifles were made on the same lines as the Mark VII S, as the ·303 in. case would not take a big enough charge to secure the required velocity.[2] Experiments in this direction had already been carried out by Messrs. Kynoch with a ·333 Jeffery rifle, but the results had been disappointing. The Supply Department thought that the problem was a manufacturing one, and could be solved by the use of sufficiently hard steel cores and cupro-nickel plated steel envelopes, so the Design Department did not reopen the question of a large calibre, but concentrated on the production of a new pattern of ·303 in. Messrs. Kynoch had put forward a design generally similar to the Roth design and manufacture of this type was already in hand. It promised to be much better than the R.L. pattern and nearly equal to the German armour-piercing bullet. In June, 1916, 15,000 were sent to France for trial and report, and meanwhile trials were carried out in England. On the evidence of these trials " it appeared to be probable that Kynoch's bullet was nearer to a solution of the problem than R.L.,"[3] and therefore the Design Department asked that manufacture of the Royal Laboratory type should cease altogether and that Kynoch's pattern should be adopted. The reports from France which came to hand in July confirmed the impression that the new pattern was a decided improvement. It was not, however, satisfactory, as its penetrating power beyond 50 yards was disappointing. Messrs. Kynoch considered that better penetration could only be secured by increased pressure, which would give the bullet higher velocity. As the safe limit of pressure in service rifles had already been nearly reached, this solution of the difficulty was not possible to any appreciable extent. The only line of advance was to increase the proportion of the weight of the core to the whole and improve accuracy by better made components. Pending these improvements, the Kynoch bullet was approved in November, 1916, under the name of Mark VII P.[4] It consisted of a cupro-nickel envelope and a core composed of two parts, a hardened steel central core and a filling between the envelope and steel core of lead and antimony. The propellant to be used with the bullet was cordite.

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[1] HIST. REC./H/1440/4.
[2] D.G.M.D./B/37.
[3] *Ibid.*
[4] *Ibid.*

Rejections of armour-piercing ammunition were frequent during the first six months of 1917, the chief difficulty being the provision of suitable steel cores, but the Chief Superintendent of Ordnance Factories said that "the whole trouble is a manufacturing one, and the difficulties can only be got over after much experience and experiment, which we are carrying out continually."[1] As regards quantity, a slight relief was obtained by getting from the King's Norton Metal Company a supply of armour-piercing bullets made on the lines of the French ·303 in. bullet with a bronze envelope and a hardened steel core.[2] At the same time, the supply department concentrated their energies on securing better sources of supply for components and greater accuracy in their finish. They obtained cores of a larger diameter, and consequently of increased weight, and a design of bullet with this core was introduced as Mark VII W. and remained the final design at the end of the war. Ammunition on a similar design was also manufactured in this country in 1918 for the United States ·30 rifle and proved by experience to be the best.

As the war went on the use of armour-piercing ammunition was much extended, and by the autumn of 1917 supplies were being demanded for the air service and for general use as well as for snipers. So far it had not been required for use against tanks, as no German tanks had yet appeared in the field. But a development in this direction was expected in 1918, and the demand would then become larger still.[3] In view of these increased and varied requirements, it was decided to abandon the policy of insisting that all ammunition must be fit for unrestricted use before it was accepted, and to grade the ammunition according to the use to which it was to be put. Thus the proportion of total rejections was considerably reduced and soon ceased to be serious, owing to the great improvements in manufacture effected by the ceaseless vigilance of the department and the loyal co-operation of makers.

During the course of the efforts to improve the armour-piercing bullets, a variety of suggestions were received from abroad and from various inventors, but they were not of much value, owing to absence of any pre-war investigation of this subject among those abroad, or of knowledge among inventors at home of information acquired by experiment during the war.[4]

II. Tracer and Incendiary Ammunition.

(a) S.P.K. Mark VII T.

A certain amount of preliminary work on tracer bullets had been carried out before the war by Major Newton, Loyal North Lancashire Regiment, at Woolwich, and a design was in readiness to meet the demands of the Royal Flying Corps. This was therefore introduced into the service. It gave a white light trace of a length of 50 to 100 yds. It proved, however, very difficult to manufacture. Rejections for inaccuracy were numerous; there was a

[1] D.G.M.D./B/37.
[2] D.G.M.D./B/994.
[3] D.G.M.D./B/37.
[4] Hist. Rec./H/1440/4.

considerable proportion of blinds and prematures; and the length of trace was insufficient. Owing to the pressure on the Royal Laboratory for output of all classes of ammunition, it was impossible to conduct further experiments there, so in the early part of 1916 the Ministry obtained part of the premises of Messrs. Aerators, Ltd., as an experimental factory, and set on foot further investigations.[1] It was believed that the cause of failure lay in the tracing composition used. Experiments were therefore made in this direction, and in June a mixture of one part magnesium to eight parts of barium peroxide was obtained, which gave promising results. A change was also made in the design of the bullet, a bronze bullet with a chamber for the tracing composition at the base being specially made by Messrs. Aerators from the material of the French bullet on which they were engaged. Extensive trials took place with this bullet at the Musketry School at Hythe, and the Commandant reported that it was "easily the best yet tested at this school. It gives a clear, bright light which can be easily observed."[2] The Director of Inspection of Small Arms Ammunition also reported "the result is excellent,"[3] and the bullet was therefore approved for issue to the Royal Flying Corps in July, 1916.[4] Originally described as "Sparklet" from its appearance and place of origin, it was now known as S.P.K. Mark VII T.[5]

(*b*) S.P.G. MARK VII G.

Considerable difficulty was experienced in the process of manufacture in boring the chamber to receive the composition, and as the pressure on the Royal Laboratory was relaxed by the supersession of the R.L. tracer, the Laboratory staff was asked to try to produce a more practical form of the design. This was successfully accomplished, and the new bullet was introduced into the service as S.P.G. Mark VII G. The Laboratory also evolved a better method of preparing the composition which gave far more regular results, while investigations carried on by Dr. Smiles, F.R.S., of University College, London, further improved the functioning powers of the bullet, and established it on a sound basis.[6] By June, 1917, it had practically superseded the S.P.K.,[7] and after that date it was in great demand, not only by the British Army, but also by France, the United States and Italy.

(*c*) BUCKINGHAM ·303 IN. BULLET.

Early in the war Mr. J. F. Buckingham, of Coventry, offered to the Admiralty a bullet of Mark VI shape which combined incendiary qualities with a smoke trace. This bullet was adopted by the Royal Naval Air Service, and a certain quantity was obtained

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[1] HIST. REC./H/1440/4.
[2] D.G.M.D./B/301.
[3] *Ibid.*
[4] (Printed) *Weekly Report*, No. 50, XII. (15 July, 1916).
[5] HIST. REC./H/1440/4.
[6] *Ibid.*
[7] D.G.M.D./C/506.

for the Royal Flying Corps. There was for a time some difference of opinion as to the relative merits of a smoke trace and a light trace, such as that of the R.L. tracer, which was the contemporary Royal Flying Corps store. The smoke trace was deceptive, and by day the light from the Buckingham bullet was insufficient. But the range of trace given by the Buckingham bullet was so much greater than that of the R.L. tracer that a demand arose from the Royal Flying Corps for a pattern of Mark VII shape.[1] This demand was met by the evolution of the Buckingham Mark II, otherwise known as Mark VII. B. The design, which was pronounced by the Director of Inspection of Small Arms Ammunition to be a marked improvement on the Mark VI type, both in tracing and accuracy, was approved on 1 July, 1916.[2] Though the evolution of the S.P.K. bullet about the same time made it uncertain how long the Buckingham bullet would continue to be required for tracing purposes, its incendiary qualities, in which lay its main value, appeared to justify its manufacture as a regular store.

The bullet, which was fitted into a ·303 in. case, loaded at first with cordite and later with nitro-cellulose powder, consisted of a cupro-nickel envelope, the nose of which was filled with a mixture of phosphorus and aluminium. A lead plug, vertically grooved in three places, was next inserted, and then a second lead plug, tapered to a point, was pressed down on to the base of the first. A hole was drilled in the wall of the envelope at the place where a chamber was created between the base of the first plug and the tapered top of the second. This hole was then sealed with fusible metal. When the bullet was fired, the composition melted, and ran down the grooves of the first lead plug into the chamber below. It melted the metal seal of the hole in the envelope and was ejected through the hole, igniting when it came in contact with the air and giving a clear bright trace during the bullet's flight. As an incendiary bullet it was designed to act against kite balloons, the theory being that when the bullet entered the balloon a spot of burning phosphorus was splashed on to the envelope; this ignited the gas escaping through the hole in the envelope and the balloon burst into flames.

Even this improved Mark VII design was by no means satisfactory. In the first place, it was quite unfit for use in a hot climate, as when the temperature was raised above the melting point of phosphorus (112 deg. F) the bullet leaked, owing to ineffective sealing. Many attempts were made to remedy this defect, apparently without success. It was also found that it had a tendency to deteriorate through keeping, and therefore all Buckingham ammunition had to be re-tested for functioning efficiency every two months (altered later to four months). Faults like these limited the usefulness of the ammunition considerably. They were, however, minor defects compared with the really serious failure in the incendiary qualities of the bullet, which was discovered immediately it came into use in the field. In December, 1916, G.H.Q. proposed to discard Buckingham ammunition in favour of Sparklet, which was just as incendiary

[1] HIST. REC./H/1440/4. [2] D.G.M.D./B/278.

as Buckingham, and possessed the merit of superior visibility.[1] At this time, however, a modification was made in the Buckingham bullet (two holes were drilled in the envelope instead of one), and this appeared to give it a better incendiary effect than the Sparklet, so it was taken into service again.[2] It was found, however, that it was still much less efficient than the German incendiary ammunition, which was a copy of the Buckingham. It was suggested, as the result of experiments in France, that a flat-nosed bullet would have better effects than a pointed one. The latter only made a small tear in the fabric of the balloon on entering and leaving it, which did not allow sufficient gas to escape for ignition ; a flat-nosed bullet would punch a circular hole which would allow a free escape of the gas.[3] Experiments on these lines were set on foot by the Design Department in July, 1917, and a longer bullet with a greater phosphorus content was produced. This bullet was reported by the Commanding Officer at the Royal Flying Corps Experimental Station at Orfordness to be several times more efficient than the standard and apparently "nearly as good as the German incendiary."[4] Firing trials carried out by the Director of Inspection of Small Arms Ammunition proved less satisfactory. The flattening of the nose affected adversely the accuracy of the bullet, the tracing was poor, and in many cases the bullet collapsed before leaving the barrel of the rifle. To overcome this last defect, it was decided to experiment with steel envelopes and stronger cupro-nickel ones. The Design Department felt, however, that the whole design of the bullet left much to be desired, and it was decided to obtain some German incendiary ammunition and study it in order to find out the reason for its superior efficiency.[5] During 1918, great improvements were effected in the Mark III type, but finality was not attained in the design of this store, and in November, 1918, experiments were still proceeding on an improved pattern.

(*d*) BROCK BULLET.

When the Germans introduced the practice of bombarding undefended towns from Zeppelins and other aircraft, it became desirable to consider the manufacture of ammunition which would have a destructive effect on enemy aircraft. No work had been done in this direction before the war, either as regards design or manufacture, although the existence of the Austrian explosive bullet was known. That bullet was of too complicated a design for manufacture at short notice, and so the Brock bullet was adopted temporarily, pending the development of a new design. This explosive bullet was manufactured in the first instance for the Royal Naval Air Service, and was afterwards approved for use by the Royal Flying Corps under the name of the B.I.K. bullet.[6] It was soon superseded as a land service store, but it remained in use throughout the war by the Naval Air Service for anti-Zeppelin work over the North Sea.[7]

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[1] D.G.M.D./B/278.
[2] *Ibid.*
[3] *Ibid.*
[4] D.G.M.D./B/278.
[5] *Ibid.*
[6] HIST. REC./H/1440/4.
[7] D.M.R.S./135.B.

(e) P.S.A. BULLET.

In the early part of 1916, an improved design was evolved to replace the Brock bullet. This was prepared by Captain Hardcastle, of the Inspection Department, after discussion with Mr. J. Pomeroy, and the bullet was introduced into the service under the name of P.S.A. While the bullet was in its experimental stage it was seen by representatives of the Royal Flying Corps, who demanded a supply. When manufacturing operations were undertaken, it was found that prematures occurred owing to the composition being nipped between the core and the envelope. To avoid this a copper tube (called a "war-head") was inserted to cover the joint, and the incendiary composition was placed in this. Trials in July gave satisfactory results and the bullet was approved on 12 August, 1916.[1]

This bullet consisted of a cupro-nickel envelope with a core of lead and antimony. The envelope had an open nose into which was inserted a copper cylinder which reached to a depth of rather more than half the total length of the bullet. The P.S.A. composition was placed in this cylinder, which was closed at the top. A small hole was punched through the top and sealed with collodion to prevent the composition exuding. The propellant used in the cartridge case was cordite.

P.S.A. ammunition could be used either from aircraft or from the ground against aircraft. As in the case of Buckingham ammunition, defects developed when the bullet was put into use on a large scale. It was found that it would not detonate except at high striking velocities, nor on a fabric containing rubber, said to be a Zeppelin fabric.[2] The Munitions Invention Department was therefore asked to undertake further experimental work, and in the latter part of 1916 a new design was evolved. The alteration consisted of the insertion of a shot in the base of the tube and the omission of the hole in the head. This change made the bullet more sensitive without added risk. It was also found that better results were obtained if the ammunition was slightly warmed. In February, 1917, the new design, which was to be known as P.S.A. Mark II, was approved, and the Air Board asked that it should replace existing supplies of the old pattern as soon as possible.[3]

The use of this type of ammunition was confined to Home Service Royal Flying Corps units, and so there was from the first no doubt about supply being sufficient for requirements.

(f) R.T.S. BULLET.

Neither the Brock nor the Pomeroy bullet contained in itself all the elements necessary for the destruction of hostile aircraft, but in combination with S.P.G. and Buckingham ammunition each achieved its purpose against raiding Zeppelins. The uncertainty which both betrayed in functioning led, however, to research for another design,

[1] D.G.M.D./A/108; D.G.M.D./B/352.
[2] D.G.M.D./B/352.
[3] *Ibid.*

and this was produced in July, 1917, by Sir Richard Threlfall. The new bullet was known as the R.T.S. bullet. As the original design proved difficult in manufacture, some modifications were made and the new model was approved as the R.T.S. Mark II bullet. It was both incendiary and explosive, and was extremely sensitive. It was designed for use against balloons, Zeppelins and aeroplanes, but was really only tested to any large extent against the last, since up till September, 1918, it was only used by the Royal Air Force at home against Gothas. Here it proved so effective that its use abroad was sanctioned, but it was never used in the field to any great extent owing to the Armistice. Experimental work continued on this bullet, and on a variant known as R.T.T. which contained high explosive instead of the R.T.S. incendiary composition, till November, 1918, and a good deal of work still remains to be done.

Among other experiments, that of using a larger calibre gun, the old ·45 Maxim, was tried in 1916, and the Royal Flying Corps were hopeful of better results from this weapon. Most of the special types of ammunition were experimented with or actually produced in this calibre, but the results did not justify expectations and work in this direction was therefore abandoned during the war.[1]

III. Modifications in Design of ·303 in. Mark VII.

(a) SERVICE BULLET.

The difficulties in manufacture presented by the Mark VII design, for which there was apparently no compensating advantage, led to the consideration of a design with only two components, envelope and core. There would probably be no very great difficulty in turning to such a design in peace time, but in view of the large number of weapons in use in various fields, it was agreed that in war time it would be impossible to accept such a design unless it were ballistically identical with the existing Mark VII so that no change of sighting would be involved. It would also have to be so nearly identical in external contour that there would be no risk of failure to function in the various forms of magazines, belts, and feed strips in use. These conditions prevented the realisation of the ideal of a bullet with two components only in war time.[2]

Design was not only modified by experience in manufacture and in the field, it was also affected by the increasing shortage of the materials required for manufacture. In 1916 the difficulty in obtaining aluminium made it desirable to find a substitute for the aluminium tip in the core of the Mark VII bullet. In May experiments were started with vulcanite, steel and china clay tips.[3] In June, Messrs. Nobel made some bullets with paper tips, and, as these appeared promising, larger quantities were ordered for experimental purposes.[4] In July, the Director of Inspection of Small Arms Ammunition reported that the paper-tipped bullets were "satisfactory in every respect and could not be distinguished frcm

[1] HIST. REC./H/1440/4.
[2] *Ibid.*
[3] D.D.G.E./EM2/529.
[4] D.G.M.D./B/283.

aluminium tips."[1] The matter was next referred for consideration to the Munitions Design Committee, who recommended that 20,000 rounds should be made by at least four different makers under varying conditions.[2] Accordingly Messrs. Kynoch, the King's Norton Metal Company, the Birmingham Metal and Munitions Company, and Messrs. Nobel were given orders for 5,000 each. Trials of bullets from these orders proved as satisfactory as the earlier ones, and as the makers had experienced no difficulty in manufacture, the use of these paper tips as an alternative to aluminium was approved on 22 December, 1916. There was some uncertainty as to the validity of the use of paper: it was thought that the enemy might say we were using infected paper as cores for bullets. The matter was put before the Army Council, who stated that bullets with paper tips do not break the Hague Convention because

(1) they are not bullets which expand easily;
(2) they are not poisonous;
(3) they are not calculated to cause unnecessary suffering.

Accordingly it was perfectly legitimate to use them. It was decided, however, to adopt the term "fibre" rather than paper in describing the new tip, since although paper was chemically a correct description of the material, its physical properties were so different that it seemed doubtful whether it could be identified as paper.[3]

This fibre rod was in general use during 1917 and 1918. At first the tip contained a core of lead to bring it to the exact weight of the aluminium tip it replaced, but experience showed that this was unnecessary and that the weight could be provided by a slight increase in length in the main lead core without affecting ballistics.[4]

In 1918, as was anticipated, the German Government raised objections to this modified form of Mark VII bullet, alleging that the paper tips contained bacteria, but eventually they extended their complaint to all bullets having a tip separate from the core, and thus included in their indictment the original Mark VII with the aluminium tip.[5] In reply to the complaint about the fibre tip, the British Government stated that the bullet did not contravene either the Hague Declaration of 1899 or the Hague Convention of 1907, and therefore it would continue in use.[6]

The introduction of the Hotchkiss gun into the service necessitated an alteration in the means employed to hold the cap in place in the cap chamber, as the action of the gun tended to produce the fault of "caps out," which seriously interfered with its functioning. It was therefore decided that ultimately all ammunition must have the cap secured by ringing in, though slabbing and other temporary expedients were adopted until all makers were able to ring in. This decision raised a difficult problem in the salvage of returned ammunition, as no method of decapping cartridges with ringed-in caps was known.[7]

[1] D.G.M.D./B/283.
[2] *Ibid.*
[3] *Ibid.*
[4] Hist. Rec./H/1440/4.
[5] *Ibid.*
[6] D.M.R.S./135B.
[7] Hist. Rec./H/1440/4.

The use by the Air Services of gear connecting the engine to the machine gun so that the firing of the gun was interrupted when the shot would be likely to strike the propeller blade raised a series of new problems as regards hang-fires, missfires, and rate of firing of the cartridge. The first investigations of these troubles showed that a large proportion of the difficulties were due to defects in the adjustment of guns and gears, but even when these had been remedied, enough difficulty remained to show that the conditions of aerial fighting demanded a much higher degree of regularity in the ammunition than could be assured in the bulk supply.

The difficulty was first met by the careful selection of ammunition for the air services. This was issued directly to the Royal Flying Corps and specially marked with a green label. Simultaneously the manufacture of ammunition specially suited for Royal Flying Corps purposes was begun, and after a few experiments a satisfactory type was evolved. This was issued to the Royal Flying Corps with a distinctive red label. It did not differ essentially from Service Mark VII, being chiefly dependent for its excellence on more careful supervision in manufacture and more exacting conditions in inspection.[1] Eventually Red Label as distinct from ordinary ammunition was manufactured not only in ·303 in. Mark VII, but also in S.P.G. and armour-piercing ammunition, all of which were used from aircraft as well as from the ground.

(*b*) DUMMY DRILL CARTRIDGE.

An important modification also took place in the design of dummy drill cartridges. The dummy in existence when war broke out (Mark IV type) consisted of a wooden bullet fitted into a defective or a used ·303 in. cartridge case. About the middle of 1916, G.H.Q. Home Forces reported that the wooden bullets were not satisfactory, and in March, 1917, G.H.Q. France also raised objections to the wooden bullet.[2] Both suggested that a metal bullet would be better. The danger of fitting a metal bullet into an ordinary case (as had already been found in the case of inspectors' dummies) was that the dummies were not sufficiently distinctive to prevent live rounds becoming mixed with them, and accidents occurred. Yet an efficient dummy was essential for training purposes, since constant practice was the only means of attaining a high rate of fire. The Design Department took up the problem and decided to alter the principle of dummy manufacture altogether, and produce a specially made article of distinctive appearance. After a variety of experiments, a new design was approved in July, 1917.[3] This (the Mark VI type) consisted of a solid bullet of cupro-nickel alloy secured in the case by two cannelures. The case was also of cupro-nickel and had three vertical indentations ·75 in. long filled with red paint. Reports of trials by the Home Forces showed that the cannelures and the indentations, combined with the distinctive metal of the case, were sufficient to mark off the dummy from the live cartridge ; and the new design was issued for both rifle and machine gun instruction.

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[1] HIST. REC./H/1440/4. [2] D.G.M.D./C/506. [3] *Ibid.*

An inspector's dummy on the same lines was approved later. In this case the cannelures would have been objectionable, so the cupro-nickel case was retained and a bronze bullet, or alternatively a Mark VII bullet with a bronze envelope, was fitted to give a distinctive appearance.[1]

IV. Propellant Powders.

At the beginning of the war, the only propellant in use for the ·303 in. Mark VII was cordite. The trials of the ·276 in. rifle had already indicated the need of a change, but no powder experimented with before the war gave as good results as Dupont, Nos. 16, 17 and 18, with which much of the ammunition purchased in America was loaded. Experiments showed that for S.P.K. and S.P.G. tracers a nitro-cellulose powder was essential, and as it was found that there were conveniences in manufacture to be obtained by allowing a general use of this powder, an alternative Mark VII specification was approved allowing the use of Dupont No. 16 or other suitable nitro-cellulose powder. Cartridges so filled were called Mark VII Z.

V. Packing Boxes and Chargers.

The necessity for grading and packing ammunition for different purposes led to the development of different modes of packing. The old method of packing in chargers and bandoliers in boxes of 1,000 rounds was largely abandoned, and boxes of various sizes were employed, distinctive coloured cases and metal tallies of various shapes being used to distinguish the different types of ammunition. A new design of ·303 in. charger, more efficient in functioning and simpler in manufacture, was also approved, while material in stock for Russian chargers was utilised for a design of chargers submitted by Messrs. Hinks, Wells & Company.[2]

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[1] Hist. Rec./H/1440/4.

[2] Hist. Rec./H/1440/4.

CHAPTER III

SUPPLY IN PRE-MINISTRY DAYS.

I. Sources of Supply.

The problem before the Army Contracts Department which dealt with the provision of small arms ammunition before the Ministry was constituted, was no small one, for not only had the heavy expenditure of the Expeditionary Force to be replaced, but equipment had to be provided for the new armies, rapidly being brought into being at home. The ammunition in use for machine guns and for the short Lee-Enfield rifle, with which all the troops in the field were equipped, was the ·303 in. Mark VII, and naturally the demands for this were enormous.

The stock in hand on 1 August, 1914, was only 29,000,000 rounds,[1] out of a pre-war production which averaged 108,306,000 yearly.[2] The existing sources of supply were the Royal Laboratory, Woolwich, which produced more than one-third of the total, and five firms, the Birmingham Metal and Munitions Company, Messrs. Kynoch, Ltd., the King's Norton Metal Company, Messrs. Greenwood & Batley, and Eley Brothers. The great centre for small arms ammunition manufacture is Birmingham, partly on account of the close connection between the industry and the metal trade which is concentrated at Birmingham, and partly because, as Mr. Arthur Chamberlain, the Chairman of Messrs. Kynoch, expressed it, " Birmingham people are born handy at the work, those of the North are not."[3] Outside the Birmingham ring the only firms who manufactured ammunition in large quantities during the war were Messrs. Greenwood & Batley, of Leeds, and the London firm of Eley Brothers.

II. Contracts placed in August and September, 1914.

Contracts for ·303 in. Mark VII placed with the trade in May, 1914, were still running in August, and a total of 24,000,000 rounds remained to be delivered.[4] This amount, together with the 29,000,000 in stock and an indefinite quantity under inspection, was all the War Office had to depend on when war broke out. On 21 August new contracts were placed with the manufacturers for a total of 158,000,000 rounds, to be completely delivered by the second week in February, 1915.[5] On 27 August, Lord Kitchener gave peremptory orders that all

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[1] Hist. Rec./R/1440/2.
[2] Hist. Rec./H/1440/1.
[3] 57/Gen. No./3595.
[4] Hist. Rec./R/1440/2.
[5] Contracts /8134.

small arms ammunition manufacturers must provide themselves with plant sufficient to double their output in six months' time.[1] Next day the manufacturers met the Master General of the Ordnance to consider the situation, with the result that further orders were placed with Kynoch, Greenwood & Batley, the King's Norton Metal Company, and Nobel. Representatives of the Birmingham Metal and Munitions Company took part in the negotiations, but no contract was placed in their name because the firm was owned by Nobel, and their output was to go towards the deliveries under the Nobel contract when they had completed the deliveries under contracts already running in their own name. Instructions to proceed with manufacture were given to Kynoch, Greenwood & Batley, and Nobel on 2 September. The King's Norton Metal Company's instructions were delayed till 8 September owing to greater difficulty being experienced in the negotiations with this firm. On 7 September Messrs. Eley were approached to take an additional order and received their instructions to proceed on 11 September.[2]

Negotiations for the signing of the formal contracts went on during September and October. All the firms had to provide new plant, and in some cases, new buildings also, and this postponed to some extent the date by which they would promise delivery. Greenwood and Batley promised a small one by the end of October, but the other firms considered that they would be unable to deliver on these contracts before January and February, 1915. Except Kynoch all firms were to complete their deliveries by the end of May: a month's extension was granted to Kynoch, because at the end of August they had undertaken, at the request of the War Office, an urgent order for 20,000,000 7·65 mm. cartridges for Belgium.[3] Thus in little more than a month from the outbreak of war arrangements were made for a supply of 327,000,000 rounds of ·303 in. ammunition, besides the production of the Ordnance Factory, which before the war was about 1,000,000 a week and was now being rapidly increased.

The provision made in the United Kingdom was supplemented by orders placed in the United States. The Remington Arms Union, the United States Cartridge Company, Peters' Cartridge Company and the National Cable and Conduit Company all took orders for deliveries in 1915. Except the Remington Arms Union, who started delivery in December, 1914, apparently on a contract placed on 26 August through the Canadian Government, none of these firms gave deliveries in pre-Ministry days. A contract was also placed with the Ross Rifle Company of Canada, but this also proved disappointing.[4]

III. Increased Provision in March, 1915.

Though further contracts for ·303 in. Mark VII were placed in the United Kingdom in the early months of 1915, it became evident in March that fresh provision must be made in order to meet the rapidly increasing demand. It seemed doubtful whether existing

[1] 57/Gen. No./3595.
[2] *Ibid.*
[3] 57/Gen. No./3595.
[4] *Order and Supply List,* No. F 60.

firms could increase their output any further, so the War Office considered the policy of introducing new firms into the industry. This had already been done as an isolated instance in the case of Messrs. Rudge-Whitworth, Ltd., with whom a contract for 2,000,000 rounds a week was placed in February.[1] This firm had exceptional opportunities for developing a successful cartridge manufacture, as they were Birmingham people connected with the cartridge machinery firm of Messrs. Taylor & Challen, and had already a skilled cartridge maker as Works Manager. But the difficulties in the way of converting this individual action into a general policy were almost insuperable. Apart from the fact that cartridge making is one of the most highly specialised industries in existence, the congested state of the metal market, the immense demands pouring in from all quarters for new plant, and the keen competition for labour of every grade rendered it extremely unlikely that new firms would be able to compete successfully with the established manufacturers or to give any appreciable output in a reasonable space of time. Messrs. Kynoch, with whom the question was discussed, stated that it was their unanimous opinion, "looked at . . . entirely from the interest and point of view of the Government," that as regards both quantity and quality the War Office would be better advised to instruct existing manufacturers to increase their works than to go to fresh people.[2] This decided expression of opinion from the principal small arms ammunition firm in the country led the War Office to abandon their scheme and to appeal to existing firms to increase their output still further.

Messrs. Kynoch, the Birmingham Metal and Munitions Company, and Eley Brothers responded to this appeal. Messrs. Kynoch offered to increase their output from 10,000,000 to 20,000,000 a week. They estimated that the new factory which they would have to build would be ready to begin production by 1 October, and would be giving its full output four months later. This offer was accepted by the War Office in March in a modified form. The firm was to increase to 15,000,000 weekly by 1 January, 1916.[3] At the end of May, however, they reopened the question and accepted the original offer of 20,000,000, which the firm hoped to attain by the end of January, 1916.[4] The Birmingham Metal and Munitions Company promised to attain an additional output of 4,000,000 per week by 27 November,[5] and Eley Brothers were instructed to increase their factory in order to attain a maximum output of 2,000,000 a week.[6]

The remaining firms were unable to offer any assistance. Greenwood & Batley stated that their reorganisation after their recent extensions was not yet sufficiently advanced to enable them to undertake fresh obligations,[7] and the King's Norton Company were suffering severely from great delay in the delivery of the machinery for their September contract and had not yet attained their promised output under this contract.[8] Nobel's organisation was included in the offer of the Birmingham Metal and Munitions Company.

[1] Contracts Firms R/2337.
[2] 57/Gen. No./3595.
[3] 94/C/43.
[4] 94/C/364.
[5] 15/Contracts/36.
[6] 94/C/51.
[7] 94/C/118.
[8] 94/C/220.

IV. Requirements and Deliveries.

(a) ·303 IN. MARK VII.

In spite of all the manufacturers' efforts to fulfil their promises, it was inevitable that deliveries should be delayed by the disorganisation of industry prevailing during the first months of the war. All the manufacturers found that their contractors for buildings and machinery failed to keep their promises, and the difficulty of getting skilled labour made output slow and uncertain, even when the premises were built and equipped. In February, 1915, Major Byrne stated that one of the reasons for placing a contract with Rudge-Whitworth was " the defects in delivery under present contracts."[1] Towards the middle of the year deliveries improved considerably, but as issues had increased sixfold, from 17,000,000 rounds in August, 1914, to 115,000,000 in June, 1915, the situation was serious, and on 1 July the stock of ·303 in. Mark VII at Woolwich was only 1,000,000 rounds.[2] That deliveries never met estimated requirements seems obvious. In a statement made by the Master-General of Ordnance on 7 August, 1914, these were given as 499,000,000 till 6 February, 1915.[3] From 1 April to 31 July they were 431,000,000.[4] With the additional requirements for February and March the total estimated requirements for the period August, 1914, to 31 July, 1915, must have been over 1,000,000,000. The total deliveries for the period were 643,727,000, made up of 119,527,000 from Woolwich, 432,777,000 from the British trade, and 91,423,000 from the United States.[5]

The closing of the gap between estimated requirements and deliveries in view was therefore the main problem before the Small Arms Ammunition Department of the Ministry when it took over the supply. The position, though serious, had its encouraging aspect. The steady growth of output during the past year was promising for the future. In August, 1914, the total output was approximately 11,000,000; in June, 1915, it was nearly 92,000,000, and in July it leapt up to 128,000,000.[6] Many of the contracts placed by the War Office had yet to materialise. Moreover, experience was already showing that the wastage in the field was not in reality as great as the War Office calculated in their estimates, and output was more nearly meeting the real requirements than the figures showed.

(b) OTHER TYPES.

The War Office experienced little difficulty with the supply of ammunition other than ·303 in. Mark VII. Demands for ·303 in. Mark VI, pistol ammunition and instructional stores, were comparatively small, and the existing sources of supply proved sufficient; while tracer and armour-piercing ammunition of temporary design to meet immediate needs was manufactured at Woolwich.

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[1] Contracts Firms R/2337.
[2] HIST. REC./R/1440/2.
[3] 57/Gen. No./3595.
[4] HIST. REC./R/1440/1.
[5] D.D.G.E./EM2/208.
[6] D.D.G.E./EM2/747.

CHAPTER IV.

MINISTRY PROGRAMMES.

I. Requirements of the War Office.

(*a*) ·303 in. Mark VII.

The largest demands made on the Ministry were naturally for the ·303 in. Mark VII ammunition. On 10 July, 1915, the War Office forwarded their estimated requirements until June, 1916.[1] Their calculations were based on the assumption that on 1 August the third new army would have been equipped with rifles and that the strength of the Expeditionary Force in rifles would be 600,000. Three more new armies were to be equipped by December, 1915, and one every month afterwards until June, 1916,[2] when the maximum establishment of the armies would be reached, and supplies would henceforth be required only to balance expenditure and wastage. The amount per rifle to be supplied until June, 1916, was calculated as follows :—

(*a*) The expenditure in the Expeditionary Force was assumed to be four rounds per man per day for 80 per cent. of the total force.

(*b*) The equipment for 80 per cent. of the new armies was 560 rounds per rifle and 200 rounds per rifle for the remaining 20 per cent.

(*c*) The equipment for reinforcements was 120 rounds per rifle.

Varying additions were made for each month for practice rounds, increasing according to the increasing establishment of the army, and to the total thus arrived at 25 per cent. was added to allow for contingencies and for machine gun requirements, which were an initial supply of 50,000 rounds per gun and a monthly supply of 10,000 rounds per gun.[3]

On this basis the requirements of the War Office for ·303 in. Mark VII until June, 1916, were as follows[4] :—

1915.		1916.	
August ..	132,000,000	January ..	234,000,000
September ..	150,000,000	February ..	250,000,000
October ..	150,000,000	March ..	266,000,000
November ..	167,000,000	April ..	282,000,000
December ..	217,000,000	May ..	298,000,000
		June ..	315,000,000

[1] D.M.R.S./135 B.
[2] D.D.G.E./EM2/197.
[3] D.M.R.S./135 B.
[4] *Ibid.*

In September, 1915, the War Office asked that provision should be made for a supply of 300,000,000 rounds a month from July, 1916, onwards. On comparing this requirement with the prospective deliveries of machine guns and rifles, the Ministry calculated that, on the basis of equipment laid down by the War Office, the numbers of machine guns and rifles available would, as early as February, 1916, be ahead of the ammunition provided. In February the requirements for ammunition, according to the estimated deliveries of rifles and machine guns, would be 280,000,000, instead of the 250,000,000 laid down by the War Office.[1] Moreover, by May and July the supply of rifles and machine guns would have overtaken the War Office requirements for these arms, and there would be a surplus available for the Allies if it were not required for British forces. The Ministry therefore asked in November, 1915, whether the Army Council's estimates were still considered adequate and what supply of small arms ammunition should be arranged for the surplus small arms which they hoped to have available.[2] To this the War Office replied in February, 1916, that the supply of 300,000,000 asked for in September was considered sufficient to meet all requirements. As regards the scale of supply for the surplus small arms, the Army Council considered that the scale for machine guns should be as already laid down, 50,000 rounds initial supply and 10,000 monthly supply per gun, while the supply for rifles should be an initial supply of 300 to 500 rounds, and a monthly supply of from 80 to 100 rounds per rifle.[3]

The position thus created, together with the possibility of having to give supplies of ·303 in. to Russia, necessitated a revision of the small arms ammunition programme. The Minister had already given authority to arrange an output of 400,000,000 rounds per month. On 10 February, 1916, he sanctioned an increased output of 100,000,000 rounds, and in April he gave authority to obtain another 50,000,000.[4] Thus the total programme for ·303 in. Mark VII before the Ministry was 550,000,000 rounds per month, the amount available after the War Office demand for 300,000,000 per month had been met to be devoted to equipping the surplus small arms and to supplying the needs of Russia.

In July, 1916, the War Office reduced their requirements to 200,000,000 ·303 in., which figure covered the supplies required for machine guns, even on the proposed heavy establishment.[5] It was decided however, that the programme of British output should be adhered to, advantage being taken of the reduction in War Office demands to cancel American contracts. Owing to the length of time that elapsed before cancellation could take effect, and to the fact that British contractors were now reaching their maximum contract deliveries, from July onwards output began to exceed requirements.[6] Moreover, the amount of wastage in the field, calculated

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[1] D.M.R.S./135 B.
[2] *Ibid.*
[3] *Ibid.*
[4] D.M.R.S./135 B.
[5] *Ibid.*
[6] *Ibid.*

by the War Office as 8 per cent., did not in reality exceed 3 per cent.[1] It seemed probable that actual expenditure was nearer 100,000,000 a month than 200,000,000, and consequently large stocks began to accumulate. On 2 November the Ministry asked the Army Council to reconsider their requirements, and these were reduced to 130,000,000 rounds per month. This figure was not to include any supplies required for the Allies.[2]

Arrangements were made by the Supply Department to reduce output in accordance with the revised requirements, and the reduction came into force in January, 1917.[3] In the meantime stocks had accumulated so rapidly that the Ministry felt justified in making new proposals. They suggested that as the Russian requirements were becoming increasingly heavy, the War Office might suspend their demands on current deliveries entirely, and take their monthly income of 130,000,000 rounds out of stock (which in December, 1916, was 1,000,000,000), until it was reduced to a figure approaching the minimum reserve of 500,000,000. Current deliveries might then be diverted to the Russian requirements. On 13 January, 1917, the War Office agreed to this proposal.[4]

In May the War Office asked that deliveries of ·303 in. should be resumed at the rate of 150,000,000 rounds a month.[5] Stocks had now become sensibly less, and even if the decrease continued normally the minimum reserve of 500,000,000 rounds would be reached in ten weeks. But heavy demands from India and other theatres of war were being made, and it had been notified by the Deputy Director of Ordnance Stores that approximately 179,000,000 rounds included in stock had been sentenced for practice only. It was reckoned, therefore, that the surplus was only two weeks' supply instead of ten weeks, and output must be raised as early as possible.[6]

The Ministry demurred considerably to this demand. In view of the extreme shortage of lead, it was a question whether it was essential to keep a stock of 500,000,000 rounds in reserve. Further, the demand for 150,000,000 per month seemed to be on the high side, since the expenditure during the 1916 offensive had so far not exceeded 110,000,000 per month. It was suggested by Mr. Alexander Duckham that an output reaching this figure by November should be arranged. He pointed out that even if expenditure went on at 150,000,000 per month the stock would not be jeopardised, since it was proposed to hold back 100,000,000 packed for Russia and Roumania, and to recover 100,000,000 from salvaged ammunition. These two additions combined with the output at the proposed rate of 110,000,000 per month would allow for an expenditure of 150,000,000 and still leave a reserve in November of 411,000,000. In view of these facts, a letter was sent to the War Office on 31 May, 1917, asking that an increase of 110,000,000 per month might be sanctioned instead

[1] HIST. REC./R/1000/17.
[2] D.M.R.S./135 B.
[3] *Ibid.*
[4] D.M.R.S./135 B.
[5] *Ibid.*
[6] D.D.G.E./EM2/1028.

of the 150,000,000 asked for. On 13 June the War Office agreed to this course, stipulating, however, that special provision should be made to increase output rapidly should it be necessary.[1]

In July, 1917, a request was received from G.H.Q., France, for an additional 20,000,000 per month to carry out a new system of musketry training. As the stocks in France were then 40,000,000 below reserve, and the amount held in England was insufficient to allow this increased requirement to be taken from stock, the War Office asked the Ministry to increase output to this extent, and a revised programme was drawn up on the basis of an output of 130,000,000 per month.[2]

In October the low state of the stocks held in England, now reduced to 168,000,000, coupled with the fact that expenditure during September had amounted to 165,000,000 while output had only reached 116,000,000 instead of the estimated 151,500,000, caused the War Office to renew their demand for 150,000,000 per month for service purposes at the earliest possible moment. To this they added a request for 25,000,000 per month for practice purposes. They suggested that this requirement might be met in part from the stock of salvaged ammunition in the country. In order to replenish the stock of service ammunition, they asked that the amount held in this country for Russia (now 167,000,000), about which negotiations had been going on since May, should be definitely handed over for the use of British troops. There was also about 100,000,000 of United States Cartridge Company ammunition, previously sentenced for practice only, which had now been passed for unrestricted use. It was suggested that this should be issued as a reserve for home defence, and that the corresponding amount of first-class ammunition now kept in the country for this purpose should be issued for use overseas.[3]

Considerable discussion ensued in the Ministry as to the advisability of complying with the War Office demand. Deputy Director-General (E) pointed out that these transfers, added to the already existing stock, would bring the amount of ·303 in. ammunition available for issue overseas up to 450,000,000 approximately. If to this were added the reserve for home defence, the ammunition in dumps and some small miscellaneous supplies, the total was raised to 646,000,000. It was therefore possible that the difference between the present output (130,000,000 a month) and the new demand (150,000,000 a month) might be met from this stock. On the other hand, Mr. Layton pointed out that there was a steady tendency for the expenditure of small arms ammunition to rise, and that there were liabilities to be met amounting to 267,000,000 (167,000,000 for Russia and 100,000,000 for volunteer replacements and requirements). On 29 November the Minister wrote to the Master-General of the Ordnance saying he "was not sure that the War Office requirements did not err on the side of safety," and he would be glad to have a further consideration of the matter since an increase could only be arranged at the expense of other war material. The Master-General of the Ordnance replied that he must press for the 150,000,000 already asked for, and it was decided to meet this requirement by an increased output.[4]

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[1] D.M.R.S./135 B. [2] *Ibid.* [3] *Ibid.* [4] *Ibid.*

In December the position of stocks was causing the War Office "grave concern." In a report to the Director of Artillery, Colonel Handley pointed out that the demands from the forces in the field were steadily increasing owing to the greater number of rifles and machine guns in the field and to the introduction of barrage fire from machine guns. The British force in Italy would have to be equipped and maintained, and there was every possibility of supplies having to be sent in the near future to Egypt and Mesopotamia, where active fighting had been in progress for some months. Therefore the reserve which the War Office had indicated as necessary in May, *i.e.*, 500,000,000 at home and 250,000,000 on the lines of communication in France, was no less essential now. Actually the reserve in France on 18 November stood at 166,000,000, and though there was a potential reserve at home of 400,000,000, only 142,000,000 of this was tangible, since the supplies held back from Russia would have to be repacked before they could be issued, and the 98,000,000 reserve for home defence had not yet been released. Moreover, during the last six months expenditure had exceeded output to the extent of 315,000,000 rounds. During December there was due out a total of 111,000,000 rounds for the forces in the field, beside 45,000,000 promised to Italy and 23,000,000 for the equipment of the volunteers. The release of these amounts would deplete the potential reserve to 221,000,000 and exceeded the actual amount the War Office could lay hands on immediately by 37,000,000. In view of this serious position it was considered that the output for the next few months should be considerably enlarged.[1] On 18 December, at a conference between representatives of the War Office and the Ministry, it was agreed that the Ministry should provide an additional 35,000,000 per month for four months in order to build up the War Office reserves. Thus the total War Office requirements from December, 1917, to April, 1918, were 185,000,000 per month.[2]

The factor governing the programme for 1918 was the great German offensive begun in March. Until that date the output of 185,000,000 a month was adhered to, but the losses and expenditure entailed in the first weeks of severe fighting in March and April necessitated an immediate revision of the programme. At the end of March an estimate of output was drawn up to produce 230,000,000 in April and 250,000,000 in May. A week later the Controller of Small Arms Ammunition was asked to get the largest possible output in May, even above the 250,000,000 suggested. But the slowness with which the new programme could be brought into operation, and the enormous losses in the field during the latter part of March and the beginning of April, made it necessary to draw on the reserves, scarcely yet built up from their previous depletion, and this was done to such an extent that by 14 April there was a reserve in England of 80,000,000 only. Even allowing for the fact that an abnormal amount of ammunition was either in transit or on the lines of communication in France, the situation was very serious, and the War Office sent an urgent request

[1] D.M.R.S./135 B. [2] *Ibid.*

to the Ministry to increase output sufficiently to build up the reserve to something approaching its normal figure, in addition to meeting the enlarged current expenditure.

The programme was therefore revised in April to bring production up to 300,000,000 a month for May, June and July. Current expenditure continued, however, so heavy that even on this programme there seemed little chance of rebuilding stock. At the end of May the War Office stated that the position was still serious: though the reserve in France had risen to 300,000,000, it was still practically nothing in England. They therefore asked that the programme should be again increased by 3,000,000 a week. There was some difference of opinion within the Co-ordinating Committee as to the advisability of increasing output still further, but the Master-General of the Ordnance was so insistent on the necessity, whatever it might cost, that there was no alternative but to accede to his wishes. In June, however, the situation at the front improved so materially that it was not found necessary to carry out the programme; in July it was definitely stated by the War Office that the increased output would not be required, and in August the position was stable enough for a comprehensive programme to be put forward up till June, 1919. This programme, as approved by the Minister, allowed for a progressive decrease in production from 300,000,000 a month in October to 180,000,000 in June, 1919.[1] It was hoped that this would allow the building up of a reserve of from 1,000,000,000 to 1,200,000,000 rounds, and with this stock in hand a comprehensive cut might be made in 1919. The signing of the Armistice in November made the carrying out of the programme unnecessary.[2]

In addition to ordinary ·303 in., requirements for Red Label ·303 in. appeared in October, 1917, when a demand for 2,000,000 a month was forwarded by the War Office. In December this was increased to 3,000,000, and by May, 1918, it had reached 9,500,000 a month, at which figure it remained till the Armistice. The value of this specially selected ammunition for aircraft work is proved not only by the growth in demand, but also by a special message sent from the Headquarters of the Royal Air Force in France in August, 1918, saying that the Red Label ammunition was giving the greatest satisfaction and urging a plentiful output in readiness for another offensive.[3]

(*b*) ·303 in. Mark VI.

The requirements for this type of ammunition were very small, all the rifles for use in the field being sighted for Mark VII; Mark VI ammunition was only needed for the colonies,[4] for some of the rifles used by Territorial regiments, and for the requirements of the Admiralty.[5] At the outbreak of war contracts were running with the Birmingham Metal and Munitions Company, and these were completed by December, 1914. A further contract placed about the beginning

[1] See Appendix I.
[2] D.M.R.S./135 B.
[3] *Ibid.*
[4] India supplied her own requirements for Mark VI.
[5] See p. 28.

of August was cancelled to make way for Mark VII ammunition, and all requirements from 1914 onwards were met by contracts placed in America.[1]

(c) ARMOUR-PIERCING AMMUNITION.

Definite requirements by the War Office for this ammunition are very difficult to trace at first. Supply was very slow in overtaking demand, and in practice the War Office demand in the early days resolved itself into a comprehensive " all that can possibly be supplied." In May, 1916, the Supply Department was asked to arrange for a stock of 500,000 Mark VII S to be built up in the United Kingdom, exclusive of the amount to be sent to France.[2] In February, 1917, the demand which was then standing at 500,000 per month was raised to 625,000 rounds a month,[3] and in September it was reduced to 500,000 ordinary armour-piercing ammunition and 20,000 specially selected for the Royal Flying Corps.[4] This was the beginning of Red Label armour-piercing as distinct from ordinary armour-piercing and was an evolution similar to that which took place in ·303 in. and S.P.G. to meet the needs of aerial warfare. From this time onwards requirements for armour-piercing ammunition were always given in the two categories, and steadily increased in amount. In December, 1917, they stood at 1,500,000 a month, equally divided between Red Label and ordinary; in August, 1918, the last demand before the Armistice, requirements were 2,300,000 a month ordinary and 1,600,000 a month Red Label.[5] The marked increase in the requirements for this type of ammunition in 1918 compared with the earlier years of the war is indicative of the developments in methods of warfare which took place during the war, but which only reached their climax in 1918.

(d) TRACER AND INCENDIARY AMMUNITION.

Owing to the experimental nature of this type of ammunition in the early days of the war, the first requirements for it show great variety and great fluctuations, and it was not till the middle of 1917 that they attained anything like regularity, and the three main types appeared as Buckingham, S.P.G., and P.S.A. The first requirement, appearing in December, 1915, was simply for flame tracer cartridges at the rate of 560,000 monthly.[6] By July, 1916, the demands for " all types of tracer bullets " stood at 6,000,000 a month.[7] After this date tracer bullets were differentiated into types, and requirements for each type were given separately. The P.S.A. demand was comparatively small, and was met by two statements of requirements, one for a total of 5,000,000 rounds in March, 1917, and another for a similar amount in October, 1917.[8] The requirements for Buckingham

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[1] HIST. REC./H/1440/2.
[2] D.M.R.S./360.
[3] D.D.G.E./EM2/529.
[4] D.M.R.S./360.
[5] D.M.R.S./135 B.
[6] C.R./4501.
[7] D.M.R.S./423.
[8] D.M R.S./135 B.

and S.P.G. on the other hand grew steadily. Between October, 1916, and October, 1917, demands for Buckingham varied from 100,000 a month down to 50,000 and back again to 100,000. In December, 1917, they were raised to 250,000 a month,[1] and in May, 1918, they totalled 750,000 a month,[2] the highest figure reached before the Armistice. The S.P.G. demand appeared first in June, 1917, when it replaced the S.P.K. type, the demand for which had been stated as 6,000,000 a month by Christmas, 1916.[3] For S.P.G. the more modest demand was 2,000,000 a month. This figure remained until the end of 1917, when the differentiation into Red Label and ordinary appears. In 1918 there was a considerable increase in requirements, the figures for Red Label being 2,500,000 to 2,000,000 per month and for ordinary 2,000,000 to 2,300,000 a month.[4]

Requirements for R.T.S. were comparatively small, since the bullet was a later development, and was still hardly out of the experimental stage when the war ended. A regular supply of 20,000 a month was asked for in March, 1918, together with an accumulation of 500,000 rounds, a reserve which was attained by June, 1918. In May the regular monthly supply was increased to 40,000, and in addition another total demand for 2,000,000 rounds was put forward with the proviso that they were to be produced "at as slow a rate as is consistent with keeping the factory going." From this it is evident that though a larger demand was anticipated had the war continued into 1919, at the end of 1918 supply was exceeding demand in this type of ammunition.[5]

(*e*) Pistol Ammunition.

The ammunition for service revolvers was Webley Mark II, and a demand for a total of 5,000,000 rounds was already standing when the Ministry took over supply. In August the Ministry asked the War Office[6] what increased quantities of ammunition would be necessary to equip the supply of 90,000 revolvers recently ordered. The War Office replied that as the expenditure of pistol ammunition had not been as great as was expected, the weekly deliveries from manufacturers might be decreased, instead of increased, an income of 600,000 per week (the estimated rate of supply was then 850,000 per week), with the existing stock, being sufficient to meet all demands.[7] Evidently stocks continued to accumulate in spite of this decreased output, for in March, 1916, the War Office stated that a further total supply of 3,000,000 would meet their requirements for Webley ammunition, and outstanding orders might be cancelled.[8] In August, however, the revised requirements for revolvers necessitated a new demand for ammunition at the rate of 500,000 per week.[9] In May, 1917, in view of the increasing demands, this was increased to 850,000 per week, and it remained at this figure throughout 1918.[10]

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[1] D.M.R.S./423, D.D.G.E./EM2/529 and D.M.R.S./135 B.
[2] D.M.R.S./135 B.
[3] D.M.R.S./423.
[4] D.M.R.S./135 B.
[5] *Ibid.*
[6] D.D.G.E./EM2/199.
[7] 94/C/655.
[8] D.D.G.E./EM2/199.
[9] 94/C/1786.
[10] D.M.R.S./135 P.

In 1917 a demand for ·45 Colt automatic pistol ammunition developed. In August two "spot" demands for 500,000 rounds and 108,000 rounds were forwarded by the War Office, as urgent demands from France had to be met and there was only a small quantity in stock. In September, as the expenditure in France had risen to 135,000 rounds per month, the War Office asked for a further provision of 100,000 rounds per month, and it was expected that this requirement would continue for the duration of the war.[1]

·455 automatic pistol ammunition was also demanded by the Royal Flying Corps in August, 1917. Supply was to be at the rate of 50,000 rounds per month, in addition to a stock of 50,000 in the United Kingdom. The monthly requirement was stated to be 75,000 rounds in November,[2] and it appears to have risen steadily during 1918, till at the date of the Armistice it was 300,000 rounds.[3] In September supplies of ·38, ·380 and ·32 Colt automatic were also demanded. Initial supplies of 30,000, 10,000 and 22,500 rounds respectively were required, and the monthly requirements would be 10,000 rounds of ·38 in., 3,250 rounds of ·380 in., and 7,500 rounds of ·32 in.[4]

(f) ·303 IN. DUMMY DRILL AND PRACTICE AMMUNITION.

The demands for ammunition for training purposes were comparatively small. On 31 January, 1916, the requirements for blank and dummy drill were stated to be 600,000 rounds of each type weekly.[5] In July, 1917, a demand was forwarded to D.M.R.S. for a total quantity of 2,000,000 dummy drill of the new cupro-nickel pattern Mark VI. The ordinary dummy drill was not, however, entirely superseded at this date since requirements were forwarded for it in September and December, 1917. In March, 1918, it was stated that the manufacture of Mark III and Mark V was to cease altogether, and dummy drill requirements were consolidated in a demand for 250,000 Mark VI per week in addition to the 2,000,000 still being delivered under the July order. The requirements for blank stood at their highest figure (3,000,000 a month) in October, 1917, after which they steadily declined till in June, 1918, they were only 1,000,000 a month.[6] The demand for practice ammunition resolved itself into a question of regulating inspection rather than of placing contracts, since it was usually met by salvaged and rejected service ammunition, which was inspected by the Director of Inspection of Small Arms Ammunition, and passed for practice purposes according to War Office demands.

(g) MISCELLANEOUS SUPPLIES.

The Supply Department had also to make provision for other requirements, generally of a minor character. In the initial stages the supply of signal cartridges formed part of its work, but as they

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[1] D.M.R.S./135 P.
[2] *Ibid.*
[3] D.D.G.E./EM2/529.
[4] D.D.G.E./EM2/529.
[5] *Ibid.*
[6] D.M.R.S./135 B.

increased in number and variety they fell outside the scope of the Small Arms Ammunition Department, and in February, 1916, they were taken over by the Trench Warfare Supply Department. The supply of rifle grenade cartridges remained, however, in the hands of the Small Arms Ammunition Department.[1]

Supplies of ammunition of special calibre were asked for at intervals. Contracts for ·22 Rim Fire ammunition were running both in England and America when the Ministry was constituted. In March, 1916, the War Office stated that owing to an accumulation of stocks contracts with British firms might be cancelled.[2] Until 1918 the supplies from America were sufficient to meet the demand (about 100,000 a month). In January, 1918, contracts were placed with Messrs. Kynoch and Eley Bros. to meet a demand for 50,000,000 rounds, and when in July it was increased to 4,000,000 a week, further contracts had to be placed with British firms, and the available capacity of the country was strained to the utmost to produce this amount.[3]

A certain number of demands were also received for large bore ammunition. To meet these the Ministry relied at first on the stocks held by small arms ammunition makers, but by the end of 1916 these were almost exhausted. An inquiry was then made into the stocks held by gun makers and sporting ammunition dealers with a view to obtaining supplies, and this revealed the same state of things.[4] Contracts were therefore placed with certain small arms ammunition firms, but in general the Ministry disliked placing these small orders with the big cartridge makers, as they interfered with the output of ·303 in. ammunition.

Orders for supplies for experimental purposes had also to be placed by the Supply Department. These were generally small "spot" demands, and merged into a regular supply when the design was approved for service. Wherever possible these orders were executed by Woolwich, for experimental work, like small orders, interfered with the output of ·303 in. by the small arms trade.

II. Requirements of the Admiralty.

(a) ·303 in. Mark VI and Mark VII.

Though the Admiralty placed most of its own contracts for small arms ammunition, supplies of Mark VI and Mark VII and small quantities of special ammunition for the Royal Naval Air Service were obtained from land service stores. Originally the Admiralty had their own contracts for Mark VI and Mark VII with Greenwood & Batley, but at the end of 1915 they agreed to suspend these to allow the firm to concentrate on Mark VII for the army, on the understanding that any requirements for the navy would be met out of War Office stocks.[5] These were allowed for in War Office estimates, and therefore do not appear as separate demands on the Ministry.

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[1] D.D.G.E./EM2/457.
[2] Contracts/2488. 94/C/422. 94/C/1798.
[3] D.M.R.S./135 B.
[4] 94/C/2179. 94/C/4189.
[5] D.D.G.E./EM2/58.

(*b*) SPECIAL AMMUNITION FOR ROYAL NAVAL AIR SERVICE.

The ammunition required by the Royal Naval Air Service was also at first supplied out of War Office stocks. No definite arrangement was made with regard to this; it developed automatically out of the practice of the Royal Naval Air Service of doing a little friendly "borrowing" from the Royal Flying Corps. As long as the navy demand was comparatively small no difficulty arose, but as the air services developed this haphazard method of supply became very unsatisfactory. In August, 1916, when the S.P.K. bullet was adopted, the Admiralty approached the Ministry of Munitions directly and asked what weekly supply could be allotted to the navy. The Ministry passed on the request to the War Office, who agreed to make provision for the navy's requirements out of the orders placed.[1] The Royal Naval Air Service appears, however, to have kept up its practice of applying to the Royal Flying Corps, since in 1917 a regular allotment of 50,000 rounds per month of S.P.G. was being made, together with occasional supplies of Buckingham and P.S.A.[2] The War Office stated that they had no "official and regular demands" for these supplies from the Admiralty. Demands made on the Ministry in August, 1917, for 250,000 a month Red Label and 60,000 P.S.A. enabled them to take up the matter, and Deputy Director-General (E) suggested that in future all Admiralty demands should be supplied through the Ministry.[3] This involved not only the requirements of the Royal Naval Air Service, but also the supplies for which direct Admiralty contracts were placed. The object of the proposed change was to secure a proper co-ordination of supplies as well as regular and sufficient provision for the Royal Naval Air Service. The Admiralty negatived the proposal, ostensibly on the grounds of inspection difficulties. The matter was brought up again by the Ministry in January, 1918, but the reorganisation of the air service automatically solved the problem of Royal Naval Air Service supplies, which was the most important point, and the subject was dropped.[4]

III. Requirements of Allies.

(*a*) ·303 IN. MARK VII.

In February, 1916, it was agreed between the British and Russian Governments that 10,000 Lewis guns which were being made to British order by the Savage Arms Company in the United States should be handed over to Russia. In April it was further agreed that 2,500,000 American rifles were also to go to Russia, and the Ministry expected to have to provide ammunition for both these arms.[5] Eventually, however, the Russians decided not to take over the American rifles, and their demand was limited to the supply of ammunition for the Lewis guns at a rate of 100,000,000 rounds per month. At a conference of 25 July, 1916, between the Secretary of State for War, the Master-

[1] D.M.R.S./423.
[2] D.M.R.S./135 B.
[3] D.M.R.S./135 B.
[4] *Ibid.*
[5] *Ibid.*

General of the Ordnance and Deputy Director-General (E.), it was decided that this request should be granted, and as the ports were closed during the winter, it was arranged that the monthly supply until December should be sent in advance.[1] By October 480,000,000 rounds had been shipped. Another 400,000,000, which would complete the Russian requirements, were to be shipped in the spring. The total Russian requirements were 800,000,000, but out of the 480,000,000 sent in 1916, 70,000,000 were given to Roumania[2]: the replacement of this was included in the 400,000,000 to be sent in the spring. By May, 1917, between 700,000,000 and 800,000,000 rounds in all had been shipped. Then difficulty was being experienced in meeting the largely increased demands of the War Office for ·303 in., so it was proposed to Colonel Belaiew, the Russian military representative in England, that the balance of the Russian requirement should be transferred temporarily to the War Office. Colonel Belaiew agreed to this course, stipulating that it should be replaced not later than 1 September, 1917. In June General Poole wired from Russia that the supply of small arms ammunition actually in the country was ample for some months and that, unless additional machine guns were sent from England, supplies of ·303 in. could be suspended.[3] In view of this information and of the increasing shortage of ·303 in. for the use of British troops, Colonel Belaiew agreed in September, 1917, that the promised replacement might be put off till 1918.[4] The question came up again in December when the whole supply of ·303 in. was being reviewed, and the Army Council then stated that they could not agree to any replacement being made until the stocks in the United Kingdom and France had reached the required reserve.[5]

At the end of 1916, Roumania asked the British Government for supplies of ·303 in. at the rate of 13,000,000 per month, and it was considered possible to supply this demand out of the excess capacity created by the reduction in War Office requirements from 300,000,000 to 200,000,000 per month.[6] An additional supply of 50,000,000 total was required in November to equip 100,000 American rifles which the War Committee had decided should be sent to Roumania. The possibilities with regard to this supply were three.

(1) The Russians might hand over to the Roumanians part of the 480,000,000 already despatched to Russia and the amount lent could be replaced early in 1917.

(2) Deliveries of ammunition from American contracts could be diverted with the rifles. The chief objection to this course was the quality of the ammunition.

(3) Ammunition might be shipped from the United Kingdom, but the difficulty in providing tonnage might be a serious obstacle.

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[1] D.M.R.S./135 B.
[2] *Ibid.*
[3] D.D.G.E./EM2/1039.
[4] D.D.G.E./EM2/1039.
[5] D.M.R.S./135 B.
[6] *Ibid.*

Eventually it was decided to adopt the first possibility, and the replacement of the ammunition thus given to Roumania was included in the 400,000,000 to be sent to Russia in the spring of 1917.[1]

In February, 1917, the French undertook the equipment of the Roumanian army, and the demand for ·303 in. was reduced to 5,000,000 a month.[2] In May it was decided to hold back an amount of 30,000,000 due to Roumania and to suspend further deliveries until the position of the ·303 in. supply at home improved. The Russian Government undertook to supply any further ·303 in. ammunition required by Roumania out of Russian stocks during the suspension of British deliveries.[3]

When British forces were sent to Italy in the autumn of 1917, it was agreed that the necessary munitions should also be furnished. In a report of 1 December, Colonel Handley said that 45,000,000 rounds of ammunition would be required to equip the rifles and machine guns sent with the troops. Eventually this appears to have been reduced to 30,000,000. As this ammunition was to equip British troops, it was treated as part of the War Office requirements and not as a separate demand, and the whole of it was ready for shipment by the end of 1917. In November, 1917, a supply of 300,000 cartridges without bullets was approved. This developed into a regular supply, gradually rising from 150,000 to 400,000 a month by July, 1918.[4] This supply was for the Italian Government, and the cartridges were to be filled with A.P. bullets to be manufactured in Italy.

(*b*) TRACER AMMUNITION.

Until the end of 1916 the Allied requirements for tracer ammunition seem to have been met by transference from stocks held by the Royal Flying Corps. The French obtained both Buckingham and S.P.G. ammunition in this way, and in September 20,000 tracer bullets were transferred to the Belgian air service to meet their needs till the end of the year.[5] In February, 1917, the Ministry proposed that in future all Allied requirements should come through the Commission Internationale de Ravitaillement and be provided either by the War Office out of stock or by the Ministry.[6] The Belgian and Italian S.P.G. requirements for 1917 were met out of stock, but the Ministry was asked to arrange a supply of bullets only (both Buckingham and S.P.G.) for the French. The requirements for these were in March, 1917, 75,000 and 300,000 per month respectively, and they steadily rose till in May, 1918, they were 1,000,000 Buckingham and 1,900,000 S.P.G. bullets a month.[7]

The War Office asked for the provision of 50,000 rounds of Buckingham for Russia and 68,000 rounds for Belgium in October, 1917, but there is no record of these supplies being approved. In 1918 there

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[1] D.D.G.E./EM2/518; /570. D.M.R.S./135 B.
[2] D.D.G.E./EM2/529.
[3] D.M.R.S./135 B. D.D.G.E./EM2/1039.
[4] D.M.R.S./135 B.
[5] D.D.G.E./EM2/1305.
[6] *Ibid.*
[7] D.M.R.S./135 B.

were no demands for tracer ammunition for the European Allies except the French ones, but their place was taken by American demands for Buckingham and S.P.G. bullets. These were to fit the ·30 cases, the standard American ammunition, and were to be supplied at the rate of 500,000 of each type monthly. In view of the heavy demands for ammunition at home consequent upon the March offensive, it was for a time doubtful if the supply could be arranged, but eventually contracts were placed and the full supply was being given in June, 1918.[1]

(c) SPECIAL CALIBRES.

In 1915 the Russians bought a quantity of Japanese rifles, but they could not obtain sufficient ammunition from Japan to equip them. In November, therefore, they asked the British Government if they could supply ·256 ammunition at the rate of 45,000,000 per month. The Minister promised a supply of 15,000,000 in March, 1916, 25,000,000 in April, and 45,000,000 per month from May onwards. At the beginning of 1917 demands were reduced to 40,000,000, and in May the supply ceased owing to the revised requirements of the War Office for ·303 in.[2]

In July, 1916, the Russians asked for 7·62 mm. ammunition, and as there was manufacturing capacity available, owing to the decreased requirements of the War Office, the Ministry arranged a supply of 52,000,000 monthly. Shortly afterwards this was increased to 78,000,000, as an additional supply of 26,000,000 per month ·256 in. asked for by the Russian Government was eventually not required and supplies of 7·62 mm. were urgently needed. The further reduction in the War Office demands for ·303 in. freed a capacity of 65,000,000 per month which it was decided to offer to Russia in order that she might be able to cancel her 7·62 mm. contracts in America, a procedure which it was estimated would save in money alone about £2,500,000 a year. Thus in December the Russian requirements for 7·62 mm. were raised to 143,000,000 a month. In January, 1917, the War Office decision to suspend their demands on current deliveries released a capacity of 60,000,000 per month for conversion to 7·62, and thus the total amount of this calibre being supplied to Russia reached 203,000,000. In the revision which the small arms ammunition programme underwent in May, 1917, this demand remained unaltered, as the Supply Department was able to arrange for the output of 110,000,000 per month ·303 in. finally agreed to by the War Office without interfering with this supply. When, however, the demand for ·303 in. was raised to 150,000,000 this was no longer possible, and supplies of 7·62 were cut down from 203,000,000 to 150,000,000 per month in October.[3] In December the Minister directed that the manufacture of Russian small arms ammunition should be completely suspended as soon as possible. A stock of completed ammunition equivalent to about six months' supply (*i.e.*, 6,000,000 to 7,000,000 rounds) was to be stored, and the Arsenal factories were to be held as a dormant reserve in case delivery was resumed in future.[4]

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[1] D.M.R.S./135 B.
[2] *Ibid.*
[3] D.M.R.S./135 B.
[4] *Ibid.*

In July, 1916, it was expected that the Ministry would be asked to provide 6·5 mm. ammunition for Roumania. The amount required proved to be 13,000,000 per month, and this supply was arranged in January, 1917. In May it was reduced to 6,000,000 a month.[1] Instructions were given in November for the supply to cease entirely as the Roumanian Government stated that they had sufficient quantities in stock to meet their requirements.[2]

In March, 1917, a Belgian demand for a total of 50,000,000 7·65 mm. was approved and supply was arranged at the rate of 6,000,000 a month.[3] When this contract was completed another for 32,000,000 was approved at the rate of 2,000,000 weekly. This contract was running throughout 1918.[4]

Up to the autumn of 1917, Russia, Roumania and Belgium were the principal Allies who asked for assistance from the British Government in the matter of supplies. Except for tracer ammunition, the French made no demands on the Ministry. They had, however, three contracts in England for Lebel cartridges. These were placed in November and December, 1914, with Greenwood & Batley, the King's Norton Metal Company, and Aerators, Ltd.[5] The agreements with these firms were made quite independently by the French Government, but they affected the programme of the Ministry considerably because the difficulties encountered by all the firms in the manufacture of the French bullet hindered their output on British contracts for ·303 in. In September, 1916, Messrs. Greenwood & Batley cancelled their contract after having delivered about 600,000 cartridges only out of the 100,000,000 ordered.[6] The deliveries of the King's Norton Company were so far behind their promises in 1916 that the French Government considered terminating this contract also, but the firm promised improvement and deliveries went on till December, 1917, when the contract appears to have been completed.[7]

Demands from the United States began tentatively in the autumn of 1917 and developed in 1918. Besides asking for tracer ammunition, the Americans requested a supply of armour-piercing bullets in April, and these were supplied at the rate of 500,000 monthly. After the pressure of the summer offensive was over, the British Government offered the American Government spare capacity in England for the manufacture of ordinary ·30 American ammunition. Negotiations were going on for the acceptance of the offer when the Armistice was signed.[8]

No supplies were required by Portugal or Serbia, and there was only a small demand from the Japanese Government for Lee-Enfield ammunition.[9] An interesting point arose in September, 1917, with regard to supplies for Greece. Messrs. Eley Brothers sent to the Ministry a letter from their Greek agent asking if they could execute

[1] 94/C/4278.
[2] P.M./C/6174.
[3] 94/C/4711.
[4] D.M.R.S./135 B.
[5] C.R./4501.
[6] D.D.G.E./EM2/767.
[7] D.D.G.E./EM2/529 and /747.
[8] D.M.R.S./135 B.
[9] D.D.G.E./EM2/202.

orders for 6·5 mm. and 7·65 mm. cartridges for the Greek Government. The matter was discussed with the Commission Internationale de Ravitaillement, and the Greek delegates on the Commission asked that any application of this kind should be met by an explicit refusal. It was most desirable to suppress all inquiries by private speculators and to supply the requirements of the Greek Government entirely through the Commission. The approval of the French officer commanding the troops in the Balkans was an essential condition of supplies being made, and the procedure hitherto adopted had been that demands from the Greek Government were submitted to the French Government, who instructed the Commission which items they were prepared to supply and which they would like the British Government to provide. As no official request was made for the supplies under discussion, it would appear that the requirements, if genuine, were met by the French.[1]

[1] D.D.G.E./EM2/1184.

CHAPTER V.

SUPPLY OF ·303 IN. MARK VII AND SPECIAL CALIBRES.

I. Position in June, 1915.

When the Ministry took over the supply of small arms ammunition from the War Office the position of the contracts was as follows :—

Firm.	*Weekly Output.*	*Remarks.*
Birmingham Metal and Munitions Company and Nobel's.	8,500,000	To be attained by 28 June, 1915.
Eley Brothers	533,000 and any further output.	Actual weekly output in June about 1,000,000.
King's Norton Metal Company.	4,000,000	Continuation contract placed 3 May, 1915.
Greenwood & Batley	1,500,000 and any further output.	Actual weekly output in June, 3,000,000, 3,500,000 to be attained by 7 August, 1915.
Kynoch	10,000,000	—
Rudge-Whitworth	24,533,000 and indefinite quantity.	—

The following contracts had also been placed by the War Office, to materialise at a later date :—

Firm.	*Weekly Output.*	*Date by which output should be attained.*
Birmingham Metal and Munitions Company.	4,000,000	27 November, 1915.
Kynoch	10,000,000	31 January, 1916.
Rudge-Whitworth	2,000,000	11 September, 1915.
Greenwood & Batley[1]	4,500,000	11 March, 1916.
Eley Brothers	2,000,000[2]	6 November, 1915.

Thus deliveries from the British trade at the end of June were estimated to be at least 25,000,000 weekly, increasing by another 21,500,000 a week by March, 1916. The Royal Ordnance Factory was giving approximately 4,000,000 a week and was expected to attain 9,000,000 by the end of the year.[3] Small deliveries were also coming in from America. On 15 July, 1915, the Supply Department stated that British promises up to June, 1916, were within 8½ per cent. of the requirements of the War Office, and if American supplies were added there would be a surplus of 22½ per cent. " Therefore the position to that date is satisfactory."[4] This judgment of the situation was soon found to be too optimistic because the actual deliveries by the trade were very far from coinciding with the promised output, and the American output was proving very disappointing.

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[1] Under negotiation.

[2] Total output, inclusive of the amount delivered under their running contract, whereas other firms' output was additional to running contracts.

[3] C.R. 4501.

[4] *Ibid.*

II. Inquiries for Further Supplies from Abroad.

In view of these facts and of the assistance that was promised to Russia in the autumn of 1915, extensive inquiries were set on foot as to the possibility of obtaining further supplies of ·303 in. Mark VII from the Dominions and foreign countries. Two contracts had been placed in Canada by the War Office, one with the Ross Rifle Company and one with the Canadian Government.[1] Inquiries as to deliveries to be expected from these showed that no reliance was to be placed on the former and that there had been a misunderstanding on the part of the Canadian Government with regard to the latter. An order for 100,000,000 cartridges had been placed with the Dominion Cartridge Company, but it was in order to meet Canadian requirements, and not on account of the British Government.[2] Thus any chance of securing immediate supplies from this source vanished. The Ministry at once instructed their agent in Canada to secure any possible output during 1916, and took up the matter with the Imperial Munitions Board. Fruitless negotiations were carried on for some months, the difficulty being that the existing capacity in Canada was required for Dominion needs, and the demand for machinery in Great Britain made it impossible for any to be sent to Canada to equip new works. In March, 1916, the matter was dropped, as the Ministry decided that the more economical policy was to concentrate manufacture in the United Kingdom.[3]

Inquiries were also instituted as to the possibility of obtaining supplies from India. There were two small arms factories at Dum Dum and Kirkee then producing Mark VI. It was thought, however, that their capacity was considerably greater than their output, and that if sufficient skilled labour were provided an output of Mark VII might be obtained. The India Office was approached on the matter, but the Viceroy strongly negatived the proposal, stating that any attempt to introduce the manufacture of Mark VII into the Indian factories would, in the existing labour situation, be disastrous to the output of Mark VI without achieving any considerable output of Mark VII. Output of Mark VI was, however, being considerably increased, and probably some of this could be spared for the British Government. As the requirements for Mark VI were already covered by existing contracts, the Ministry did not pursue the matter further.[4]

Inquiries were also made as to the possibilities of supply from other Dominions and from Spain, but without result. The capacity of the Dominions was only sufficient to meet their own needs, and the only plant available in Spain was so small and incomplete that it was not worth while to acquire it.[5]

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[1] Contracts/1690. 94/C/283.
[2] D.D.G.E./EM2/90.
[3] D.D.G.E./EM2/128. For the subsequent history of the Ross Rifle Contract, *see* Vol. XI, Part IV, Chap. IV.
[4] C.M./021.
[5] D.D.G.E./EM2/155.

III. Increased Output from British Sources.

Disappointed in their attempts to get supplies from external sources, the Ministry fell back on the home trade and on Woolwich, whose output was steadily increasing. In September, 1915, the Minister sanctioned an increased output from British firms by approximately 25 per cent. of the existing contracts. The Supply Department at once instituted an inquiry as to the possibility of getting this increase from existing manufacturers by balancing plant, speeding up processes of manufacture and working an increased number of hours. All the firms promised to increase their output, but the Ministry only took up the offers made by Kynoch, the Birmingham Metal and Munitions Company and Nobel. It seemed doubtful whether the smaller firms could attain the increases they promised, and the King's Norton Company and Greenwood & Batley both had contracts with the French Government for Lebel cartridges, which the Ministry considered should be pushed forward before any extensions of their British contracts were undertaken. In December, 1915, it was arranged with Nobel that they should work up to an output of 2,000,000 a week by 30 May, 1916, and continue at this rate till three months after notice of termination.[1] Negotiations were begun with the Birmingham Metal and Munitions Company in February to increase their output by another 4,000,000 weekly, the total output to be attained by 27 May.[2] In March Messrs. Kynoch were asked to balance their plant in order to obtain a total output of 23,000,000. No actual date by which this increased output was to be attained was laid down; the company firmly refused to be bound by any clause in the agreement in this respect, though they hoped to get the output by about the end of July.[3] These two new contracts provided an increased supply of 7,000,000 weekly; for the remainder that was necessary to provide the increased 25 per cent. sanctioned, the Ministry relied on Woolwich, which was expected to attain an output of at least 14,000,000 a week.

A further increase was made in September, 1916, when it was arranged that Kynoch should increase their output to 25,000,000 a week by December, 1916.[4] In November a fresh contract was made with Rudge-Whitworth (who had terminated their contract of February), by which they were to achieve a delivery of 3,500,000 to 4,000,000 weekly by 9 December.[5] With these increases the maximum output from the British trade was reached, and the contract capacity of the different firms was as follows:—

Kynoch	25,000,000	per week.
Birmingham Metal and Munitions Company	15,500,000	,,
Greenwood & Batley	8,000,000	,,
King's Norton Metal Company	4,000,000	,,
Nobel	2,000,000	,,
Eley	2,000,000	,,
Rudge-Whitworth	3,500,000	,,
Total	60,000,000	,,

[1] 94/C/1423.
[2] 94/C/1601.
[3] 94/C/1810.
[4] 94/C/3118.
[5] 94 Firms R./325.

Counting the output of the Ordnance Factory, the capacity in the United Kingdom, exclusive of the new Government Cartridge Factories,[1] averaged from the end of 1916 320,000,000 monthly.

IV. Cancellation of American Contracts.

While the output in the United Kingdom was rising steadily, the requirements of the War Office were reduced. So much capacity was freed by the reduction of July, 1916, that the Supply Department raised the question of cancelling the American contracts. This step was desirable from the point of view of economy alone, the price of American ammunition being roughly £8 10s. per 1,000 compared with £6 10s. for British ammunition.[2] It was even more desirable from the point of view of the quantity and quality of the supply. The ammunition produced by the United States Cartridge Company (more than 50 per cent. of the whole) was regarded by the War Office as suitable for emergency use only, and much of it was sentenced for practice at home. The American contracts were also greatly in arrears. On 15 July, 1916, the Remington Arms Union was nearly 209,000,000 behind, the National Cable and Conduit Company 118,000,000, and Peters Cartridge Company 96,000,000. The Supply Department therefore recommended that the American contracts should be cancelled as soon as this could be done with safety. By October, the increase in the stocks in the United Kingdom and the probability that the War Office would still further reduce its requirements, made it possible to decrease the total income of ·303 in. ammunition. On 17 October the Minister sanctioned the cancellation of all the American contracts, and supply from this source entirely ceased by April, 1917.[3]

V. Supplies for the Allies.

The decreased requirements for ·303 in. ammunition enabled the British Government to place a considerable capacity at the service of the Allies. As early as January, 1916, the heavy demands to be made on British industry by Russia were foreshadowed in the request made by the Russian Government for a supply of ·256 Japanese ammunition. Japan had recently supplied Russia with a large quantity of rifles, but could not provide ammunition to equip and maintain them. It was therefore decided that Great Britain should supply 10,000,000 rounds weekly as long as the rifles were serviceable,[4] and Messrs. Kynoch and the Ordnance Factory were asked to undertake the manufacture. A running contract for 5,000,000 weekly was arranged with Kynoch, terminable at three months' notice, and the firm's deliveries of ·303 in. were correspondingly reduced from 11 February. The date for the attainment of the full 5,000,000 weekly was stated in the contract as 10 June, but the firm encountered unexpected difficulties in manufacture, and in October it was extended to 10 November.[5] They actually attained a good output long before November; their deliveries in May being over 20,000,000.[6] The

[1] See Chap. VII.
[2] D.M.R.S./135 B.
[3] *Ibid.*
[4] D.M.R.S./135 B.
[5] 94/C/1637.
[6] D.D.G.E./EM2/747.

Ordnance Factory output, which was to attain its maximum of 5,000,000 weekly by the end of June, was also to be at the expense of ·303 in. Woolwich experienced considerable difficulty with the manufacture of the Japanese bullet, and their output was more behind than Kynoch's. In July, when, according to the estimates, they should have attained their maximum output of 21,700,000 monthly, their accepted cartridges were only just over 3,000,000. But by the end of 1916 the supply from both sources had reached a steady 40,000,000 to 43,000,000 per month.[1]

The next demands from Russia were for 78,000,000 rounds a month of 7·62 mm. ammunition. It was decided that this should be manufactured in two of the new Government Cartridge Factories (G.C.F.'s 1 and 2) so that the dislocation of manufacture which would be occasioned by the changing over in old factories might be avoided. But when in October Messrs. Greenwood & Batley, who had recently cancelled their contract for Lebel cartridges, approached the Ministry with a suggestion that this plant should be converted for British use, it was decided that a proportion of the 7·62 mm. ammunition should be manufactured upon it. The Russian demand was urgent, and could not be met by the Government Cartridge Factories before August, 1917, at the earliest, while the Greenwood & Batley plant could easily be converted. A further advantage was that the firm had already had experience in making the Russian case and bullet owing to a Russian machinery contract which they had, and they also had a filling plant at Abbey Wood. Some of this Russian machinery could be utilised in the factory and replaced in time to ship to Russia in the spring. Accordingly the firm was given a running contract, terminable at the usual three months' notice, for a weekly supply of 2,000,000, the full output to be attained by 16 February, 1917.[2]

In November it was decided that another 65,000,000 a month should be given to Russia, and that the work should be undertaken by G.C.F. 3 and by some of the manufacturers in place of their ·303 in. output. Messrs. Greenwood & Batley were therefore instructed to change their output of ·303 in. in their Albion Factory to 7·62 mm. as early as possible. The plant was to be altered and added to where necessary in order to give its full output of 8,000,000 per week: the delivery of 7·62 cartridges was to begin on 15 March, 1917, and reach the full quantity by 21 July, 1917. Thus the total amount of 7·62 mm. to be produced by the firm was 10,000,000 a week.[3]

In January, 1917, consequent on the decision to increase the amount of 7·62 mm. to be supplied to Russia, arrangements were made with other firms and with the Ordnance Factory to take up the manufacture of 7·62. Messrs. Kynoch were to utilise the whole of their plant then on ·303 in., *i.e.*, a capacity of 20,000,000 a week, and to get their full output by 30 June.[4] The Chief Superintendent of Ordnance Factories was instructed to cut down the Woolwich production of ·303 in. to 4,500,000 a week, and to arrange an output of 4,500,000 7·62 mm.

[1] D.D.G.E./EM2/518.
[2] 94/C/3731.
[3] D.D.G.E./EM2/842. 94/C/3925.
[4] 94/C/4369.

weekly.[1] Eley Brothers were also instructed to change over to 7·62 mm. on their old plant, which was ultimately to be merged in their new Government Cartridge Factory.[2] Thus in the spring of 1917 three-fifths of the existing capacity in the country (exclusive of Government Cartridge Factories) had been changed over to the manufacture of Russian ammunition.

The needs of Roumania and Belgium necessitated further changes. In January, 1917, the King's Norton Company were instructed to change over part of their plant to 6·5 mm. in order to give an output of 3,000,000 weekly by the end of April. As by this time their output was exceeding their contract rate of 4,000,000 weekly, they continued to give an output of ·303 in. at the rate of 1,500,000 a week. Another change was made in May, when, owing to the altered requirements of Roumania, the firm were instructed to reduce their output of 6·5 mm. to 1,500,000 a week and to resume ·303 in. output at the rate of 3,000,000.[3]

Messrs. Nobel were selected to undertake the Belgian ammunition and instructed to alter and extend their plant to make it suitable for the manufacture of 7·65 mm. cartridges at the rate of 1,000,000 to 1,500,000 per week till a total of 50,000,000 had been delivered. Deliveries were to reach 250,000 a week seven weeks from the date of receiving material to start manufacture and to reach the full quantity not later than eighteen weeks from the date of receiving material.[4]

As a result of the changes in the War Office requirements for ·303 in. in May, 1917, it was decided that the manufacture of ·256 Japanese ammunition should cease. On 23 May Messrs. Kynoch were instructed that their contract for this type of ammunition would end in three months and that, according to their agreement, they should reconvert their plant and commence output of ·303 in. at the earliest possible date.[5] The Ordnance Factory was also told to change over to ·303 in. about the same date. The Supply Department was anxious to avoid interfering with the output of 7·62 mm. cartridges, but when the demand of the War Office rose from 110,000,000 to 150,000,000 a month it was impossible to attain this without sacrificing the Russian output to some extent. Early in November Messrs. Kynoch were instructed to change over from 7·62 mm. to ·303 in. to the extent of 6,000,000 per week, so that their output stood at 14,000,000 per week 7·62 mm. and 11,000,000 per week ·303 in. Reductions were also made in the output from the Ordnance Factory and Messrs. Eley Brothers.[6]

VI. Position in December, 1917.

The decision of the Minister in December that the manufacture of Russian small arms ammunition should be suspended radically

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[1] D.D.G.E./EM2/857.
[2] 94/C/3323.
[3] 94/C/4278.
[4] 94/C/4711.
[5] 94/C/1637.
[6] D.D.G.E./EM2/1004.

altered the whole situation. The programme of manufacture had to be thoroughly revised, and the following allocation of orders for 1918 was suggested by the Supply Department :—

Factory.	·303 in.	Dormant reserve for 7·62 mm.
Ordnance Factory	—	14,000,000
Birmingham Metal & Munitions Company	4,000,000	5,000,000
Nobel's[1]	—	—
Eley and G.C.F.4	—	—
King's Norton Company[2]	3,000,000	—
Greenwood & Batley	5,000,000	—
Kynoch	18,000,000	6,000,000
Rudge-Whitworth	—	—
G.C.F.1	4,500,000	—
G.C.F.3	3,000,000	—
Total per week	37,500,000	25,000,000
Total per month	150,000,000	100,000,000

This scheme was sanctioned by the Minister on 22 December.[3] The suggestion to stop manufacture entirely at Woolwich was due to the considerable difficulties which had lately been experienced there on account of air-raids, transit congestion, high cost of labour at the Arsenal, and food and housing difficulties. The stopping of supplies of ·303 in. to Russia and Roumania, and the termination of the 6·5 mm. contract, as well as the suspension of 7·62 mm. deliveries made this course feasible, since the capacity in the country at the beginning of 1918 was considerably in excess of the estimated requirements. According to the scheme, none of the factories would be working up to its full capacity, and it was suggested that the smaller ones, Nobel, Eley, and Rudge-Whitworth, could be entirely dismantled and used for other purposes.[4] The proposal to remove small arms ammunition manufacture entirely from Woolwich was strongly opposed by the Chief Superintendent of Ordnance Factories, chiefly on account of the dislocation of labour which it would involve. The matter was under discussion when events in the field in March, 1918,[5] rendered it probable that the Woolwich output would again be required. The matter was therefore dropped, though it was revived again in July, when a sub-committee of the Woolwich Committee of Enquiry was appointed to report on the desirability of continuing the filling of ammunition and the production of small arms ammunition at the Arsenal.[6]

[1] Still working on 7·65 Belgian ammunition.
[2] 1,500,000 weekly of 6·5 Roumanian. Working out notice of termination given 26 November, 1917.
[3] D.M.R.S./135/B.
[4] *Ibid.*
[5] D.D.G.E./EM2/1454, 1579.
[6] Sec./Gen./2239.

VII. Increased Output in 1918.

The demand put forward by the War Office for a largely increased supply necessitated a revision of the programme sanctioned in December, 1917, and the Supply Department put forward the following proposals :—

Factory.	April.	May.
Ordnance Factory	12,000,000	12,000,000
Birmingham Metal and Munitions ..	6,000,000	6,000,000
King's Norton Company	4,000,000	3,000,000
Greenwood & Batley	2,500,000	6,000,000
Kynoch	23,000,000	23,000,000
Rudge-Whitworth	3,000,000	3,000,000
G.C.F.1	2,000,000	4,500,000
G.C.F.3	5,000,000	5,000,000
Total per week	57,500,000	62,500,000
Total per month	230,000,000	250,000,000

This did not represent the maximum capacity of the factories, and as the demands of the War Office increased in April and May, the Supply Department correspondingly increased the output from the factories. Early in April manufacturers were instructed to give their maximum output during May, June and July, to attain which night shifts were worked, the Home Office restrictions with regard to hours of labour were suspended, and a special appeal was made to the workpeople to sacrifice their Easter and Whitsuntide holidays in order to meet the urgent demand from the front. The result of these efforts is seen in the jump from 43,000,000 to 50,000,000 in output during the first week in April. High water mark was reached in the third week of April with 80,000,000, and from this time till the end of July the weekly output ranged from 73,000,000 to 63,000,000. The maximum steady output which could be obtained from the factories in working was, however, 300,000,000 a month, and when the War Office demands exceeded this limit, the question of starting up a new factory had to be faced. The Controller of Small Arms Ammunition demurred strongly to the idea on account of the probability that demand would have fallen before output began to take place in large quantities, and this would entail waste of effort at a critical moment as well as over production in the future. But as the War Office insisted on compliance with its demand, the Supply Department began preparations for starting up C.F.6 at Woolwich, which had been closed down on the reduction of output in 1917, and was being used for storage and breaking up ammunition. While these preparations were going on, the War Office intimated that events in the field rendered it unnecessary to proceed with the larger programme. The department, therefore, fell back to the 300,000,000 monthly output, which continued till the end of October.

Preparations were in progress for reducing to 250,000,000, and turning some factories over to American ·30 in. ammunition when the Armistice was signed. Three months' notice was immediately given to terminate contracts, and supplies fell off rapidly in December.[1]

In order to increase the supplies of ·303 in. Mark VII in 1917, the Supply Department turned its attention to a stock of salvaged ammunition lying at Woolwich. When it was sorted a good deal of it was found to be American, and the department stated that "apart from Peters, American small arms ammunition has so many faults that it will probably not be worth while to try and clean and recap any of this ammunition. . . . It would appear from the condition of the boxes that in many instances the boxes have been opened, and as soon as it was observed that the ammunition was American, they have been thrown on one side as useless."[2] Early in July a meeting of contractors and Ministry representatives was held to discuss how the ammunition should be dealt with. The amount involved was 150,000,000 rounds valued at £1,000,000, whereas as scrap, its value would only be £300,000. Eventually, it was decided that the contractors should settle the matter among themselves, and they agreed that it would be better to concentrate the work in one factory rather than distribute it throughout the trade.

Messrs. Kynoch undertook the work of dealing with the salvaged ammunition, stating that they had a suitable building for the work. The cost of equipping it, which was estimated as £10,000, was borne by the Ministry.[3] The chief difficulty in arranging the contract was the question of inspection. It was obvious that under the circumstances Messrs. Kynoch could not be held responsible for the functioning of the ammunition, so it was decided to agree with the firm on the method to be employed and appoint an inspector to see that the work was properly carried out.

Though instructions were given for the work to be started at the end of July, considerable delay ensued, partly owing to the failure of the contractor to deliver the machinery, and partly because the Ministry did not approve of the drying apparatus chosen by the firm, and the procuring and erecting of new apparatus occupied a considerable time. In October the firm reported that it would be two months before the vacuum dryer would be ready for use, and the Ministry instructed them to use their own hot air cupboards temporarily in order to save time and employ their workpeople.[4] Output began in April, 1918, the total for the month being over 13,000,000. The Controller of Small Arms Ammunition stated that for June, July and August it was hoped that the amount of salvaged ammunition fit for unlimited use would be 14, 16 and 22½ million rounds. This estimate seems to have been fairly accurate, since Kynoch's

[1] D.M.R.S./135 B. D.D.G.E./EM2/529.
[2] D.D.G.E./E.M.2/529.
[3] Actually it was £12,145, as additional processes were afterwards arranged, and more machinery required.
[4] D.D.G.E./EM2/1105.

output for June and July was over 19,000,000. It fell in August to 17,500,000, and steadily declined from that date. Not all the salvaged ammunition was fit for unrestricted use; some of it appears as practice ammunition, but at a time when every round was urgently needed, the experiment more than justified itself by the amount that it added to the greatly depleted stocks.[1]

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[1] D.M.R.S./135 B. D.D.G.E./EM2/529.

CHAPTER VI.

SUPPLY OF SPECIAL TYPES OF ·303 IN. AMMUNITION, PISTOL AMMUNITION, AND INSTRUCTIONAL STORES.

The supply of special types of ammunition involved comparatively few questions of policy or of finance. It had, however, its peculiar difficulties. The variety of the demands, both as regards type and quantity, and the limited nature of the sources of supply, together with the constant changes in design and the intricacy of much of the work, made the development of manufacture a task requiring infinite patience. It was largely due to the ready and willing assistance given by the Ministry to inventors and manufacturers and to the untiring efforts of the Royal Laboratory that technical difficulties were overcome and that supplies were, generally speaking, placed on a satisfactory footing.

The activity of the Royal Laboratory in this respect was one of the most valuable aspects of its work. In the early days of the war, Woolwich supplied the only tracer and armour-piercing ammunition that was in use, and when this proved inadequate to meet new developments in the field, the staff of the Laboratory were untiring in their efforts to obtain improved types of cartridges. Besides this, the Royal Laboratory undertook the manufacture of most of the special types of tracer cartridges in order to supplement the work of the trade in this direction, and in the early days, when unexpected difficulties were constantly appearing and deliveries were a dubious question, its output often saved the situation.

I. Armour-piercing Ammunition.

Of all the special types of ammunition an efficient armour-piercing bullet provided the greatest problem. In June, 1916, owing to adverse reports on the Mark VII S pattern, instructions were given that it should be superseded by the Mark VII P pattern. This was Kynoch's pattern and orders were placed with the firm for a supply. The output was, however, very slow, chiefly on account of the difficulty of obtaining steel cores, and the December deliveries were only 120,000 as against an estimated output of 500,000. In February, 1917, to supplement Kynoch's supplies, Woolwich was instructed to take up the manufacture, and as Messrs. Kynoch would have to give up work on armour-piercing ammunition when they changed over their main output from ·303 in. Mark VII to 7·62 mm. the Birmingham Metal and Munitions Company were asked to take up the work. It would, however, be some time before they got over the experimental work involved, and in the meantime Kynoch's deliveries were being steadily rejected on account of their failure to

penetrate.[1] At the end of March the firm said that it was useless to continue manufacture under these circumstances and that they had stopped all work upon armour-piercing bullets. The most hopeful source of supply at this date was Woolwich, whose efforts had succeeded in producing a bullet which would penetrate an 8 mm. steel plate at 200-250 yards, and whose output for April was nearly 355,000 as against Messrs. Kynoch's 68,000.[2]

Most of the manufacturers were asked to help in solving the problem, and experiments were undertaken by Messrs. Eley Brothers, Messrs. Nobel, the King's Norton Company and Messrs. Greenwood and Batley. Messrs. Nobel and the King's Norton Company both offered designs, but as these were no improvement on the Kynoch type of bullet no steps were taken with regard to supply.

The position was decidedly improved in August, 1917. This was largely due to the appointment of a technical expert in the Small Arms Ammunition Department, who was responsible for an improved design and steel analysis. The supplies from the Royal Laboratory showed better accuracy and better penetration, and for the first time the deliveries were about equal to the War Office requirements. Commenting on the position, the Supply Department said, "Generally speaking, the A.P. industry is now in a reasonably healthy state." The output for September was so satisfactory, "thanks to the good work of R.L.," that the Supply Department was able to take up the question of selecting special armour-piercing ammunition for the Royal Flying Corps on the same lines as the special ·303 in. Mark VII ammunition that was being supplied for aircraft work by the King's Norton Company and Messrs. Kynoch.[3]

II. Tracer and Incendiary Ammunition.

(*a*) Buckingham Bullet.

The supply of tracer ammunition offered much the same difficulty as the armour-piercing ammunition. In July, 1916, the output of R.L. tracer manufactured by the Royal Laboratory and Messrs. Eley was 200,000 weekly, but as the type had not proved altogether satisfactory in the field, it was not proposed to increase supplies any further. The experiments of Mr. Buckingham during the early part of 1916 had resulted in the evolution of the Buckingham Mark VII type and preparations were made for its manufacture on an extended scale. Orders were placed with Messrs. Eley for bullet envelopes which were to be sent to Mr. Buckingham's works to be filled, and then to Rudge-Whitworth to be loaded up into cartridges. But the bullets when they left Mr. Buckingham's works proved so faulty that in August the Director of Inspection of Small Arms Ammunition complained that "these bullets are almost useless,"[4] and so the Ministry arranged that Rudge-Whitworth should take over the plant installed at Mr. Buckingham's

[1] D.G.M.D./B/37.
[2] D.D.G.E./EM2/529.
[3] *Ibid.*
[4] D.G.M.D./B/278.

works and execute his order as part of a contract for 3,000,000 complete cartridges at the rate of 250,000 a week.[1] This arrangement fell through eventually, and, in spite of his shortcomings in manufacture and of a decision taken in June that inventors should not be allowed to undertake manufacture, the Ministry had to fall back on Mr. Buckingham for the bullets, which were loaded into cases at Woolwich.[2] From this time onwards, since no other source of supply offered, the Ministry set to work to assist Mr. Buckingham in improving his output both in quality and quantity. In November, 1916, it was stated by the Supply Department to be "satisfactory."[3] During 1917 and 1918 he was able to meet the increased demands due to the larger British requirements and to the French demand for bullets for loading into French cases, and at the same time the quality of the bullets decidedly improved.

The ordinary Buckingham tracer was a ·303 in.; in March, 1917, an order was placed for an experimental ·45 in. tracer. The ·45 in. S.P.G. tracers had a poor incendiary effect, and it was hoped that better results would be achieved with a Buckingham bullet.[4] In October a sample lot of ·45 in. bullets was submitted, but manufacture was not continued, as the War Office had stated meanwhile that supplies of ·45 in. tracer ammunition were no longer required.[5]

(b) BROCK ZEPPELIN BULLET.

In the early part of 1916 the need for an incendiary bullet was met by the Brock Zeppelin bullet, an order for 500,000 being placed with Messrs. Brock of Sutton on 15 May. The firm did the filling only, complete cartridges with special bullets being supplied to them. They experienced such difficulties in manufacture that the question of cancelling the contract was considered in July, but as the bullet appeared more sensitive than the Pomeroy, which was still in the experimental stage, it was decided to proceed with the order. The contract was completed in December, and then, as there were good supplies in stock and the firm had other urgent contracts requiring completion, filling was suspended indefinitely.[6]

(c) P.S.A. BULLET.

The manufacture of Pomeroy bullets was undertaken by Messrs. Eley Brothers, Messrs. Nobel, and Mr. Pomeroy. An order was placed in August, 1916, with Messrs. Eley for 500,000 war heads and 500,000 cartridges with Pomeroy bullets. It was arranged at first that the entire 500,000 should be filled with P.S.A. composition and loaded up by Nobel, who had erected new buildings for the work. Later, however, Nobel's order was reduced to 400,000 approximately and the remainder of Eley's components were to be filled by Mr. Pomeroy. Minor difficulties delayed Eley's output at first, but by the end of September the Supply Department stated that "work

[1] 94/C/2770.
[2] D.G.M.D./B/278.
[3] D.D.G.E./EM2/529.
[4] D.G.M.D./B/278.
[5] D.M.R.S./423.
[6] D.D.G.E./EM2/529. 94/C/4219.

generally is proceeding satisfactorily." By November the output was sufficient to supply the Admiralty if supplies were required. The requirements of the Royal Flying Corps for this type of ammunition were comparatively small, since it was only used by the home service; and in 1917, though the output was small, the contractors were not being pressed to increase deliveries, but were urged to concentrate their efforts on other work.[1] Delivery proceeded during 1918 at the rate of 200,000 a week until August, when the Aircraft Department stated that sufficient reserves had been built up for all future requirements and contracts might be cancelled.[2]

A ·45 in. P.S.A. bullet was also in course of manufacture in 1916, Messrs. Eley supplying the cartridges and Mr. Pomeroy doing the filling. Apparently, however, this was in the nature of an experimental order, and did not continue, since the only steady ·45 in. output recorded is the R.L. type with an S.P.G. filling.[3]

(*d*). Sparklet Bullet.

After Messrs. Aerators had spent a considerable time in experimenting, an order for Sparklet bullets was placed with them in August, 1916. They experienced considerable difficulties both in the manufacture of the bullet and in obtaining a satisfactory tracing composition. Woolwich was therefore asked to undertake the Sparklet bullet, and their early attempts at manufacture proved so successful that they were instructed to cease making the R.L. tracer and arrange for an S.P.G. output of 1,000,000 a week. In October Messrs. Eley were instructed to change over from the R.L. tracer to the S.P.G. type. Meanwhile Messrs. Aerators had been struggling with their difficulties with their own S.P.K. mixture with very little success, so in January, 1917, the Ministry decided to send them S.P.G. bullets and tracing composition from Woolwich in the hope that they might be able to load them satisfactorily. These continued difficulties delayed the firm's output considerably, and had it not been for the "highly satisfactory" nature of the Woolwich output, supply would have been far more behind requirements than it was. At the end of March the total output of S.P.G. tracers reached 1,000,000 a week.[4]

At this date the Royal Flying Corps stated that the French were producing a much more efficient tracer than the British. It was believed by the Supply Department that this was attained by sacrificing output. British Manufacturers had concentrated on quantity rather than quality and had obtained even under these circumstances "a far better tracer than was thought possible in the early stages." It was decided to ask the War Office to reduce their requirements in order that makers' attention might be concentrated on the quality of the ammunition, and the reduction in the demand in April, 1917, gave the required opportunity.[5] This was so well utilised that when, in the autumn of 1917, the War Office demands were increased, quality as

[1] D.G.M.D./B/352.
[2] D.M.R.S./135 B.
[3] D.G.M.D./A/108.
[4] D.G.M.D./B/301.
[5] D.D.G.E./EM2/529.

well as quantity was satisfactory. Although heavy demands were made in 1918, the quality remained excellent, and it was reported from the Headquarters of the Royal Air Force in France in August, 1918, that "Red Label S.P.G. was giving the greatest satisfaction."[1]

(e) R.T.S. BULLET.

The latest development in special types of ammunition was the R.T.S. bullet. The Air Board asked for supplies in August, 1917, and after small experimental orders had proved satisfactory, it was decided at the end of September to proceed with a trial order of 10,000 rounds. This developed into a regular supply in March, 1918. As secrecy in manufacture was essential, the Ministry decided to erect a special factory for the filling of the ammunition and to carry it on as a national factory. It was administered by the Supply Department with Mr. J. F. Buckingham as manager. The site selected was at Coundon, near Coventry. Part of the land was held on lease by Mr. Buckingham and some of the remainder was owned by the Coventry Corporation. As it was intended that this land should be used after the war for the extension of the Coventry reservoir, the Ministry decided that the buildings to be erected should be of a temporary nature only. Three existing sheds on Mr. Buckingham's land were purchased as the nucleus of the factory, and to these were added further sheds and two brick built magazines, the most substantial part of the buildings. As the factory was designed simply for the production of R.T.S. ammunition and the requirements for this were comparatively small, it was quite a small one. The estimated total cost was £7,250,[2] and the labour employed when the factory was in full swing in March, 1918, was only 10 men and 66 women.

All the early work of construction was of a temporary nature: there was no proper office accommodation, and only a temporary system of drainage. This was partly because it was as yet uncertain whether the efficiency of the bullet would justify its manufacture on any large scale, and partly because of the urgency of the Royal Flying Corps' demands. By the middle of September construction was sufficiently advanced for manufacture to be carried on; the first output of 1,900 was given during the week ending 17 November, and by December the trial order of 10,000 was completed. The Flying Corps reported that the accuracy of the ammunition was good; it was very sensitive and functioned over a much longer range than the Buckingham cartridge.. It was therefore decided to continue the manufacture, and in January, 1918, construction work at the factory, which had been in abeyance for some weeks, was started afresh with a view to making the factory a more permanent and more convenient building.[3] Production increased rapidly during 1918, rising from 4,000 weekly in January to 20,000 in March, and by June the estimated weekly delivery of 200,000 was being made. It was carried on after the Armistice on a smaller scale until September, 1919, when it ceased entirely, and the small amount of experimental work remaining was transferred to the Enfield Small Arms Factory.[4]

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[1] D.M.R.S./135 B.
[2] C.R./2913 (May, 1918).
[3] D.D.G.E./EM2/1149; /1169.
[4] HIST REC./H/1122/83.

III. Pistol Ammunition and Instructional Stores.

Little difficulty was experienced with the supply of pistol, dummy and blank cartridges. The policy of the Ministry was to keep the supply in the hands of the firms who had been producing before the war. The cartridge for the service revolver, Webley Mark II, was made by the Ordnance Factory, and also by Kynoch and Eley Brothers, with whom contracts were running when war broke out. The supply was continued by them at weekly rates of delivery which varied with the requirements of the War Office until April, 1917, when, owing to the inability of these firms to increase their delivery rates sufficiently to meet new demands, an order was placed with the Birmingham Metal and Munitions Company for 100,000 a week.[1] This firm also took a running order for automatic pistol ammunition in April, 1917, but this appears to be the only instance of a big manufacturer doing this work.[2] The work was new to the firm, and in order to meet requirements until regular deliveries could be obtained, the Ministry bought up the stocks of all the principal sporting ammunition makers.[3]

Dummy and blank cartridges were supplied largely by the Ordnance Factory. Most of the trade firms also had contracts at one time or another. In placing orders for blank cartridges with Messrs. Eley, Rudge-Whitworth, and Greenwood & Batley, the Supply Department stated that the principle followed was to place these orders with firms who did not cast or roll their own strip, so that they might be partially relieved from the loss involved in selling their scrap cases at prices fixed by the Ministry, many of the rejected ·303 in. ball cases being quite suitable for blank ammunition.[4] Ammunition of second quality for practice purposes was also being supplied by the trade in 1918, because the amount of practice ammunition obtained by salvage or by re-inspection of rejected service ammunition was not enough to meet the demands of the War Office. This second quality ammunition does not seem to have been specially manufactured, but was obtained from that which was rejected by the firms' own inspectors for delivery for service purposes.[5]

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[1] 94/C/3139.
[2] D.D.G.E./EM2/529.
[3] *Ibid.*
[4] D.D.G.E./EM2/529.
[5] D.M.R.S./135/B. D.D.G.E./EM2/529.

CHAPTER VII.

THE GOVERNMENT CARTRIDGE FACTORIES.

I. Negotiations for Government Cartridge Factories.

The immediate reason for the establishment of national factories by the Small Arms Ammunition Department was the increased output of 150,000,000 rounds sanctioned in the spring of 1916.[1] Most of the existing organisations in England had by this date been developed to their utmost extent, the American manufacturers had proved broken reeds, and inquiries had shown that there was little hope of developing any other external sources of supply. Thus Government enterprise seemed the only hope of attaining any further large output. It was proposed that new factories should be established for a total output of 36,000,000 rounds of ·303 in. Mark VII weekly. One with an output of 6,000,000 a week was to be erected at Woolwich under the control of the Chief Superintendent of Ordnance Factories, the others were to be managed on behalf of the Government by selected small arms ammunition firms. Messrs. Kynoch, the Birmingham Metal and Munitions Company, and the King's Norton Company were first approached to undertake the work. The last two firms undertook to manage factories producing 12,000,000 and 6,000,000 a week respectively, but the negotiations with Messrs. Kynoch, who were to undertake the remaining 12,000,000, came to nothing. The firm did not like the idea of managing a factory separate from their works at Birmingham, and an inherent part of the Ministry's scheme was to decentralise manufacture in order to tap fresh sources of labour. It was next suggested that Messrs. Greenwood & Batley and Eley might undertake the remaining amount. Arrangements were made with Messrs. Eley for producing 6,000,000 weekly, but the scheme for bringing in Messrs. Greenwood & Batley did not mature, and the remaining 6,000,000 were not placed.[2]

II. General Scheme of Agreements.

The entire management of the factory at Woolwich (G.C.F.2) was in the hands of the Chief Superintendent of Ordnance Factories, and therefore its history forms part of the history of the Arsenal. The other three factories were controlled by the Ministry, and negotiations were begun in March, 1916, with a view to arriving at formal agreements with the managing firms. The general lines of the agreements were the same for all the firms, but the specific details varied with the circumstances of the individual firms and the nature of the Ministry's previous dealings with them.

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[1] *See* Chapter IV., p. 20.

[2] C.R./4501.

Acting as agents for the Minister of Munitions, the companies agreed to purchase the necessary land and erect and equip the factories at the cost of the Ministry. All expenditure was to be subject to the approval of the Minister, and all plant and machinery were to remain the property of the Minister. In order that the work of construction might not be delayed until the negotiations were completed, a clause was inserted in the agreements to the effect that any work already done with the approval of the Minister should be paid for by the Minister at the net cost, plus 10 per cent. profit.

The factories were to produce ·303 in. Mark VII, but the Minister was at liberty to alter the type of ammunition to be produced if necessary. In this case the Minister was to pay for any additional plant required, compensate the company for any loss of bonus occasioned by the change, and fix a new standard price for the cartridges if the costs of production were affected by the change. The Minister might also suspend production for any period of time, and the buildings and machinery were to be kept in good repair by the companies.

The costs of production which were to be borne by the Minister were to include—

(*a*) Cost of material.

(*b*) Wages on production.

(*c*) Fuel, light and power.

(*d*) Upkeep of buildings, roads, plant, machinery and renewal of tools.

(*e*) Establishment charges of the companies attributable to production.

(*f*) Cost of the delivery of cartridges either to Park Royal or Woolwich.[1]

(*g*) Amount of the premiums for insurance against fire and enemy risks which but for the agreement would have been paid by the companies.

(*h*) Amount to which the companies were entitled by way of management fees.

Production costs were not to include any loss arising from explosion, nor any amount for depreciation or interest on capital, and the companies were not to be liable for any insurable risk against which, under the terms of the agreement, no insurance had been effected.

A standard price was fixed in the agreements to form the basis for determining the bonus to be paid for economical working. This

[1] The Minister might order delivery elsewhere, but in that case he was to pay any additional cost of transport.

was liable to variation according as the price of the materials manufactured rose or fell below the standard price of materials stated in the agreement. The sliding scale was as follows :—

Material.	Variation in pence in price per 1,000 cartridges in respect of each complete £1 increase or decrease in price per ton of materials (except last two, where variation of 1d. per lb. shall be taken).	Basis price compared with which the variation is to be calculated.
		£ s. d.
Copper in case	1·87	135 0 0 per ton.
Spelter in case	·8	110 0 0 ,,
or		
Brass Strip	2·67	147 0 0 ,,
or		
Brass Cups	3·00	170 0 0 ,,
Copper in bullets	·521	135 0 0 ,,
Nickel in bullets	·13	185 0 0 ,,
or		
Cupro-nickel strip	·662	185 0 0 ,,
or		
Cupro-nickel cups	·75	220 0 0 ,,
Lead Rod	1·84	32 10 0 ,,
Copper strip in caps	·079	163 0 0 ,,
Propellant	5·25	3 2 per lb.
Fulminate of mercury	·018	9 6 ,,

This scale held good for all the firms, but in addition aluminium ingots, with a variation of ·095d. on a basis price of £155 per ton, were added to the King's Norton scale, and aluminium rods with a variation of ·095d. on a basis price of £196 7s. to Eley Brothers' scale. Scrap values to be credited to the cost of production were added in the case of G.C.F.'s 1 and 3 in February, 1919. This point did not enter into the original agreements, because scrap prices were not controlled in 1916.[1]

Besides varying with the fluctuations in the price of materials, the standard price was to vary as the rate of wages was increased or decreased. If the cost of production exceeded the standard price by more than 20 per cent., the excess was to be paid by the companies up to the amount of any bonus which might be payable under the agreement, unless they could prove that the rise in cost was due to causes beyond their own control. For the purpose of ascertaining the costs of production, special account books were to be kept by the companies, and were to be open to examination by representatives of the Ministry at any time.

Payments to the managing firms were to be as follows :—

(*a*) A fee for the services of the companies in designing, supervising and carrying out the construction of the factories

[1] P.C.7/59.

calculated as a percentage of the cost of construction. If the companies delayed this work from causes within their own control, the Minister might reduce the fee proportionately, or give notice to terminate the agreement, on condition of indemnifying the companies for any liabilities in connection with the work down to the date of notice of termination.

(*b*) A management fee, out of which all wages for employees from the rank of foremen upwards were to be paid.

(*c*) A bonus on economical working, calculated as a percentage of the difference between the standard price and the cost of production of all accepted cartridges. The bonus was to be paid quarterly, but adjusted at the end of every year, so that the actual bonus might be determined on the year's working. No bonus or management fee was to be paid on any cartridges rejected owing to faults in manufacture. Special letters were given to all the firms exempting their fee for construction services, management fee and bonus on economy from excess profits duty.

Though representatives of the Minister might enter upon the premises and make suggestions as regards management and efficient working, they were not directly to interfere with the control of the factory by the companies. The companies were to appoint and pay—

(*a*) The whole of the staff engaged upon the construction and equipment of the factory.

(*b*) The staff necessary for the supervision, organisation and conduct of the factory, including managers, clerks and foremen in each department.

They were also to engage and train such employees as would be required to work the factory efficiently. The Minister was to pay £4 for each operator's training, which was not to be less than three weeks, and £20 for the training of each toolmaker and machine-minder. The period of training for these was to be at least ten weeks.

Materials for the manufacture of cartridges were to be bought exclusively from or through the Minister. Funds were to be advanced by the Minister, to provide for the necessary payments for these and any other liabilities incurred under the agreement, so that the companies should not be obliged to meet them out of their own funds. The companies had the right to reject any material which they considered unsuitable, and any dispute on the subject was to be settled by a committee of four persons, appointed severally by the Minister, the Chief Superintendent of Ordnance Factories, the Chief Inspector, Woolwich, and the company concerned. The company's nominee was not, however, to be a servant of the company.

The dates from which delivery was to begin differed in the various agreements, but in general it was stated that the companies were to carry out their agreements with the greatest expedition possible with a view to securing the maximum of economy and the earliest available output. The companies were not to be held responsible for delay due to scarcity of labour or any other causes beyond their control.

If the Minister decided at any time not to proceed with the agreements, he could give notice of termination on payment of compensation on terms specially arranged with each managing firm.

If during the ten years following the end of the war the Government wanted small arms ammunition manufactured in the factories, the companies were to be entitled to manage them, and would be bound to do so :—

(*a*) if the cost of production during the war had been less than the standard price by 8s. per 1,000 or more ;

(*b*) if the Government were willing to enter into a contract for a minimum amount for a minimum time.

As regards the disposal of the factories after the war, each of the companies was to have the option, during the lifetime of any children of Queen Victoria and for 21 years after the death of the longest lived, to purchase the land, buildings and machinery, if the Minister were willing to sell, at a price less by 5 per cent. than any other offer.

Both the King's Norton Company and Messrs. Eley Brothers had further options on the purchase and use of the factories which were not included in the agreement with the Birmingham Metal and Munitions Company. The King's Norton Company had the option to purchase at any time any part of the land, buildings or plant at a price considered sufficient by the Minister to make good the difference between the factory as a going concern and the value of the part not purchased. The firm was also entitled to have the use of any buildings in which the manufacture of cartridges was either suspended or discontinued. Messrs. Eley Brothers had the same option of purchase as the King's Norton Company, but the time during which it might be exercised was limited to the lifetime of any children of Queen Victoria or to 21 years after the death of the longest lived. They also had the right to use any part of the buildings not required by the Minister.

The agreements were to be subject to the general conditions of contract of the Ministry except in so far as they conflicted with the special conditions of the agreements, and to the provisions of the Arbitration Act of 1889.[1]

[1] 94/C/1747 ; /1781 ; /2136.

III. Details of Arrangements with each Firm.

This was the general framework of all the agreements ; the special details were as follows :—

	Birmingham Metal and Munitions Company.	King's Norton Metal Company.	Messrs. Eley Brothers.
Estimated Costs.	£330,000	£227,000	£301,155.
Construction Fees.	5 per cent on the first £300,000. 4 per cent on any excess. A bonus of 1 per cent. of the difference between the total cost of construction (*i.e.*, including fee payable to the company) and £350,000. The fee and bonus were not to exceed in the aggregate £16,500.	5 per cent. on the first £200,000. 4 per cent. on any excess. A bonus of 1 per cent. of the difference between the total cost of construction and £227,000. The fee and bonus were not to exceed £11,000.	5 per cent. on the first £250,000. 4 per cent. on any excess. A bonus of 1 per cent. of the difference between the total cost of construction and £301,155. The fee and bonus were not to exceed £14,362.
Bonus on Economical working.	25 per cent. of the difference between the cost of production and the standard price of all accepted cartridges.	25 per cent. of the difference between the cost of production and the standard price of all accepted cartridges.	50 per cent. of the difference on the first 2,000,000 accepted in each week, and 25 per cent. for any excess accepted in each week.
Management Fee.	2s. 3d. per 1,000 accepted cartridges.	2s. 6d. per 1,000 accepted cartridges.	2s. 6d. per 1,000 accepted cartridges.
Standard Price.	120s. per 1,000	120s. 6d. per 1,000 ..	121s. 6d. per 1,000.
Wages Variant.	For every 2½ per cent. increase or reduction on the average rate of wages paid during the six months ending 6 March, 1916, an increase or reduction of 5·40d. per 1,000 accepted cartridges.	For every 2½ per cent. increase or reduction on the average rate of wages paid during the six months ending 6 March, 1916, an increase or reduction of 5·40d. per 1,000 accepted cartridges.	Such amount as, in the opinion of the Minister, is equivalent to a variation of 2½ per cent. in the rate of wages for every 2½ per cent. increase or reduction in the rate of wages.
Rate of Delivery.	1,000,000 weekly, six months from the date of agreement and an additional 1,000,000 every fortnight thereafter until 12,000,000 weekly was attained.	500,000 per week to begin with. 6,000,000 per week as soon as possible.	3,000,000 a week as soon as possible, increasing to a maximum of 8,500,000 as soon as possible, and including any cartridges produced under any previous agreements.

Birmingham Metal and Munitions Company.	King's Norton Metal Company.	Messrs. Eley Brothers.
Compensation if the Ministry should decide not to continue the agreement.		
If the decision were taken before the factory was ready to produce, or within three months of that date, no compensation was to be payable ; but if the factory had been in active production for not more than 16 weeks, then a payment at the rate of £1,000 a week (including any sums payable as management fee) for every week of production up to 16 weeks.	If the factory were ready to begin production but had not actually begun £2,000 was to be paid ; if production had been going on for not more than one month £3,750; if for not more than two months £5,250 ; if for not more than three months £6,500.	If the factory were ready to begin production but had not actually started £2,000 was to be paid ; if production had been going on for one month or less £3,570 ; if for more than one month and less than two months £5,250 ; if for more than two months and less than three complete calendar months £6,500. The Minister was to relieve the company of any financial responsibility to members of the staff who might claim salary in lieu of notice.
Minimum post-war Contracts.		
2,000,000 a week for 20 consecutive weeks.	1,250,000 a week for 20 consecutive weeks.	1,500,000 a week for 20 consecutive weeks.

IV. Special Arrangements with Messrs. Eley Brothers.

Special arrangements were made with Eley Brothers, and their contract differs in important respects from those of the other two firms. The output of 2,000,000 a week from the firm's old factory had only been attained by means of advances for plant and materials, which were to be repaid by instalments calculated as a fixed sum for every 1,000 cartridges delivered. When the negotiations for the management of the Government Cartridge Factory were begun there was still a certain amount of these advances to be repaid. It was therefore arranged that the company should continue to produce at the rate of 2,000,000 a week under their existing contract until the Government Cartridge Factory was erected and sufficiently equipped to continue the output at 2,000,000 weekly. The machinery paid for by means of Government advances which was running in the old factory was then to be removed by degrees and installed in the new factory at the cost of the Minister, and the firm was to pay to the Ministry any balance still outstanding of sums advanced by the Ministry either for plant or material. The whole of this old plant would thus become the property of the company and would be purchased by the Minister at the original cost, plus the cost of fitting up, less 10 per cent. per annum up to the date of transfer for depreciation. This purchase money was included in the estimated cost of the factory. The effect of this arrangement

was to concentrate all the manufacture of small arms ammunition by Eley Brothers in G.C.F.4 and the existing contract with the firm was automatically cancelled.

A further clause was inserted in Messrs. Eley's agreement to the effect that all the caps required for the manufacture of cartridges under the agreement should be purchased from the company, and the Ministry was also to buy fulminate of mercury from the firm if they could supply at as low a price as other firms.[1]

These complicated agreements necessitated a great deal of negotiation with the managing firms. Emendations of common conditions were discussed between the three firms before they were submitted to the Ministry, and when these were finally settled individual points remained to be considered. Referring to his negotiations with the manufacturers, Deputy Director-General (E.) said in May, 1917, "I have found the managing firms in question most reasonable people, and they have a considerable degree of patriotism and desire to help the Ministry."[2] In this attitude of the firms and in the readiness of the Ministry to see their point of view and assist them in their difficulties lies the secret of the success which attended the negotiations. The formal contracts were not signed until May and June, 1917,[3] but this did not delay the construction of the factories, as the work was proceeded with under heads of agreements signed with the firms in April and May, 1916.[4]

V. Changes in the Original Scheme.

While the factories were under erection two important changes were made in the original scheme. In view of the request of the Russian Government in July, 1916, for 7·62 mm. ammunition, the Ministry decided to devote the capacity of G.C.F.1 (managed by the Birmingham Metal and Munitions Company) and G.C.F.2 (Woolwich Arsenal) to this type of ammunition instead of ·303 in. At the end of the year the decision to increase largely the supplies to Russia made the Ministry follow suit with G.C.F.3 (King's Norton Company) and G.C.F.4 (Eley Brothers). Thus all the Government Cartridge Factories originally designed for ·303 in. Mark VII were converted into factories for Russian ammunition.[5] This delayed to some extent the equipment of G.C.F.'s 1, 2 and 3, as new machinery had to be ordered, but not that of G.C.F. 4, which was considerably behind the others in construction.

The second change was the reduction in the output originally planned. Output from all the factories was cut down by one-half as part of the wholesale reduction that took place in January, 1917. Thus the output from G.C.F.1 became 6,000,000 per week, and that from G.C.F.'s 2, 3 and 4 3,000,000 per week, forming a total of 60,000,000 a month instead of 120,000,000 as originally planned.[6] By

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[1] 94/C/1781.
[2] *Ibid.*
[3] The agreements are, however, dated from the time heads of agreements were signed.
[4] 94/C/1747; /1781; /2136.
[5] D.D.G.E./EM2/822.
[6] *Ibid.*

this change a considerable amount of machinery was released for diversion to other firms who were to make 7·62 mm.: *e.g.*, much of the G.C.F.1 machinery went to Kynoch, and the factories were enabled to work on a day shift only, whereas they had originally been designed for both day and night work.

VI. Modification of Agreements.

These changes entirely altered the conditions under which the managing firms were producing small arms ammunition, and in accordance with the intention of the original agreements they sent a joint letter to the Ministry in May, 1917, asking that the agreements might be modified. Besides the loss to the firms which resulted from reduction of the total amount to be paid as management fees, and the additional expense involved in the manufacture of 7·62 mm. the amendment of the laws which dealt with profits from munitions making cut down considerably the profits which the companies had expected to make when they made the agreements. Under the Finance Act, the exemption of the management fee and bonus from excess profits duty no longer held good, with the result that the amounts to be paid to the companies would be, as the firms pointed out, "a most inadequate return for the labour and services involved."[1] They therefore asked that this point should be met, as well as the losses involved in the changes in type and amount of output, when the agreements were modified.

The Ministry did not consider it legitimate to include the question of the Finance Act in the scope of the new agreement, as nothing had been said in the original agreements about the companies being indemnified in the event of methods of taxation being altered. They advised the companies to put their case before the Inland Revenue authorities, and to submit a statement for the consideration of the Lubbock Committee on contract prices. As regards the legitimate question of alteration in output, they asked the firms to put forward suggestions for the modification of the agreements. The Birmingham Metal and Munitions Company proposed that the standard price of 7·62 mm. should be 143s. per 1,000, and that the variation in pence in the price of cartridges should be altered to correspond with the different weights of metal used in 7·62 mm. ammunition. In order that the management fee might remain at the level fixed in 1916, they asked that it should be raised to 3s. per 1,000. They further asked for compensation for their loss of bonus due to the change of manufacture and to the delay in supplying cups to the Russian specification. This compensation they proposed should be fixed at £1,000 a week for the first sixteen weeks after production began.[2] The King's Norton Metal Company proposed that the standard price for 7·62 mm. should be 144s. per 1,000, and the management fee should be increased to 3s. 6d. a 1,000 to meet the difference due to decreased output. They further suggested that the economy bonus should be raised to 70 per cent. of the difference between the cost of production and the standard

[1] P.M./R.S.C./2047.

[2] D.D.G.E./EM2/1418.

price, instead of 25 per cent. in order to make up for the loss they had sustained owing to the change of manufacture.[1] G.C.F.4 was dealt with on different lines. As the factory was to be closed down, Eley Brothers considered that the working out of costs on the relative bases of ·303 in. and 7·62 mm. would be waste of time, and they would prefer to settle matters for a lump sum. The firm was therefore asked to submit a claim.[2]

The negotiations started on these bases proved long and complicated. The Ministry's attitude towards the settlement may be deduced from a minute by the Assistant Financial Secretary: "It should be borne in mind that arrangements with these firms include the disclosure by them of the inner working of the cartridge departments of their business, one which hitherto they have most jealously guarded . . . . Payments are therefore partly in the nature of consideration for goodwill and very special services."[3] In spite of this liberal point of view on the part of the Ministry, settlements with G.C.F.'s 1 and 3 were not finally made till September, 1918. The chief bone of contention was the standard price. The Ministry considered that the new standard prices proposed by the companies were out of all proportion to the actual costs of manufacture, and insisted that they must be revised. Eventually the agreements with the two firms were modified. The terms arranged with G.C.F. 3 were as follows:—The managing firm agreed that the standard price for 7·62 mm. should remain at 120s. 6d. per 1,000 as in the original agreement, but as a *quid pro quo* the economy bonus of 25 per cent. was to be paid for the whole output of 49,000,000 cartridges at the rate at which it was earned during the five weeks when production reached its maximum, *i.e.*, 3,000,000 rounds a week, and when the cost of production was therefore lowest. During the period of changing over from 7·62 mm. to ·303 in., *i.e.*, nine weeks, and for subsequent manufacture, the provisions regarding bonus and standard price in the original agreement were to apply without change to the actual production of ·303 in. cartridges. With regard to the management fee, during the period of changing over the original figure of 2s. 6d. per 1,000 was retained, but this management fee was to be paid on a fixed amount of 24,000,000 cartridges, irrespective of actual output. After the change over was made, and the increased output of ·303 in. contemplated from May, 1918, was obtained, the management fee of 2s. 6d. was to be reduced to 1s. 6d. per 1,000 in respect of all cartridges delivered in excess of the 6,000,000 weekly contemplated under the original agreement.

It was reckoned that this compromise involved an additional £1,000 by way of management fees, together with an unascertained sum as bonus on 7·62 mm. cartridges above the amounts contemplated in the original agreements, but as an offset to this, it was hoped that there would be a saving in the future because of the reduction in the management fee for all output above 6,000,000 a week. Treasury sanction was given to this settlement on 9 September, and a supplementary agreement was signed by the company.[4]

[1] D.D.G.E./EM2/1421. [2] P.M./R.S.C./2047. [3] *Ibid.*

[4] P.C.7/59. The actual terms of the modified agreement with G.C.F. 1 cannot be given as the file containing them (P.C.7/72) cannot be found.

The claim which Messrs. Eley were asked to put forward was not submitted till August, 1918. It could be divided into two parts, claims for amounts to which the firm was entitled under the agreement and which only required verification as to the correctness of their figures, and claims which needed discussion and adjustment on account of the alteration in the output of G.C.F.4. The principal items under the former heading were £14,562 as construction fee, £5,276 as fee for training workpeople, £15,905 for machines transferred from Messrs. Eley's works to G.C.F.4, and £7,164 for bullets supplied to G.C.F.4 by Messrs. Eley. These claims were found to be in order and were paid by the Ministry. More difficulty was experienced in dealing with the claims under the second heading, the chief of which were the management fee, the bonus for economy and compensation for the waiving of the firm's rights under their agreement with regard to the management of the factory. After much negotiation a settlement was reached in December, 1918. To compensate the firm for their reduced output, the management fee was raised from 2s. 6d. per 1,000 to 5s. per 1,000 on all cartridges accepted, approximately 41,500,000. In place of the bonus for economy and in full settlement of all claims in respect of reduced output and of the taking over of the factory by the Air Board, the Ministry offered a sum of £15,000, and in addition a sum of £1,500 to cover the extra cost of management after the stoppage of production until the Air Board took over the management. In consideration of these payments Messrs. Eley were to waive all rights under the agreement except the option of purchasing any of the machinery from G.C.F.4 remaining unsold at that date at a price 5 per cent. lower than the price at which similar machines were being sold by the Ministry. Treasury sanction was obtained for this arrangement on 14 December, and in March, 1919, the firm agreed to accept it as a final settlement of all claims under the agreement of May, 1916.[1]

In 1918 the Government Cartridge Factory agreements needed further supplementing, because a practice had arisen whereby the factories supplied components, tools, gauges and other articles connected with the manufacture of cartridges, either to one another or to an outside contractor. The basis of remuneration to the managing firm provided in the agreements applied to finished cartridges only, and as the practice developed, the question of adjustment to meet the new conditions arose. After considerable discussion it was agreed in May that such sales of "side lines" should take place under the following conditions :—

(1) The basis of remuneration to the managing firm should be 4 per cent. on the cost of production on any order up to £250 value, and 3 per cent. on any order exceeding this amount.

(2) Sales to another Government Cartridge Factory should be on the cost plus percentage basis, or at the cost price of the receiving factory, whichever should be the higher.

(3) Sales to contractors should be arranged at prices approved by the Contracts Branch.[2]

[1] P.C.7/13.

[2] P.C.7/17.

VII. Land.

The sites selected for the factories were at Blackheath (Staffordshire), Blackpole (Worcester), and Edmonton. G.C.F.1 at Blackheath had an area of about 68 acres; the site at Blackpole, though for a smaller factory, was 67¼ acres in extent, while the site for G.C.F.4, adjoining Messrs. Eley's existing works at Edmonton, was 13 acres. Possession of the land was taken under the Defence of the Realm Act before June, 1916, and on 23 June the Ministry approached the Treasury for approval to purchase the sites. About 64 acres of the Blackheath site were owned by Sir Charles Holcroft, who, after bargaining, agreed to a price of £125 per acre. The price for the remaining land was £225 per acre, and there would be compensation to tenants as well. The total purchase price for this property was estimated at £10,000. Of the Blackpole site, 51 acres were owned by Wall's trustees and 16¼ by Lord Hindlip, and it was considered that a fair price for this property would be £7,000, including compensation to tenants. The Edmonton site belonged partly to the Great Eastern Railway and partly to other owners, and Sir Howard Frank valued the whole property, including houses and compensation to tenants, at £9,000. Sanction was therefore requested for a total sum of £26,000 for the three sites.[1] This was given on 11 August, 1916, being included in the sanction given for the construction and equipment of the four factories at a total cost of £1,539,000.[2]

VIII. Erection and Equipment of the Factories.

Instructions to proceed with their arrangements for the construction of the factories were given to the Birmingham Metal and Munitions Company at the end of March, 1916[3]; the firm actually started work on 23 May, and seems to have got ahead with its buildings earlier than either of the others. Though a good deal of building work still remained to be completed in the spring of 1917, the main buildings were sufficiently complete for the first two units of the machinery to be installed by December, 1916. The King's Norton Company were instructed to begin work on 8 May, and their buildings seem to have been fairly complete by February, 1917. Messrs. Eley were considerably behind. Instructions were not given to begin work till 27 July, and, though the firm began construction promptly enough on 1 August, delay in building ensued. In April, 1917, some of the buildings were not yet roofed in, and the loading factory was not finished by the end of June.[4] All the firms suffered from the usual difficulties of delay in delivery of materials and lack of labour, though the Ministry aided them as far as possible by obtaining priority for them in both respects.[5] In the winter months the severity of the

[1] 94/Nat./119, 152, 153.

[2] C.R./2913. Statement *re* Capital Expenditure on National Factories. May, 1918.

[3] 94/C/1747.

[4] D.D.G.E./EM2/1218.

[5] D.D.G.E./EM2/869.

weather considerably impeded all building operations, and Messrs. Eley seem also to. have suffered from the air raids. The Birmingham Metal and Munitions Company suffered more than either of the other firms from difficulties with regard to the supply of water, power and light. G.C.F.3 had the advantage of a canal from which to draw its supplies of water for all purposes other than drinking, but G.C.F.1 had to make special pumping arrangements in order to obtain an adequate supply, and a water tower was built at G.C.F.4. The two provincial factories obtained their power and light from the local supply company, which in the case of G.C.F.1 was not very satisfactory, but in G.C.F.4 these were included in the installation of the factory.[1]

The equipment of the factories was arranged by units in order that production might begin at the earliest possible moment. A good deal of the machinery was supplied by Messrs. Greenwood & Batley, who had a large order on hand for 7·62 mm. machines for the Russian Government. As during the winter it was impossible to ship the machinery to Russia, it was arranged that some of it should be diverted to the Government Cartridge Factories and replaced in the spring. There does not seem to have been any great delay in the delivery of the machinery, owing to the action of the Ministry, who kept a steady watch on the contracting firms, and urged deliveries forward if they showed signs of falling behind. By the end of February four units were practically in position at G.C.F.1, and at G.C.F.4 plenty of machines were delivered for the installation of the first two units. G.C.F.1 was, however, delayed to some extent by the non-appearance of the loading machines. These were not completely delivered till December, 1917, and though the loading shops worked day and night shifts they were unable to keep pace with the output of components.[2]

IX. Capital Expenditure.

The estimated cost of construction for G.C.F.'s 1, 3 and 4 when the agreements were drawn up was £330,000, £227,000 and £305,155 respectively. This included the cost of the land, but not the construction and architects' fees for each factory, as these were mentioned separately in the agreements with the managing firms. At 31 December, 1917, the actual cost of the factories exceeded the estimated cost. Owing to the reduction in programme, part of the plant provided in the original layout of the factories had not been erected, but this reduction was balanced by the decision to change the type of ammunition to be manufactured while the factories were in course of construction. This entailed expenditure which would have been avoided had the original scheme been carried out, or even if the decision to change had come earlier, and it was this additional expenditure which largely accounted for the excess

[1] D.D.G.E./EM2/529. [2] *Ibid.*

over estimates. Further expenditure had to be incurred at G.C.F.'s 1 and 3 when the change to ·303 in. took place in the spring of 1918. At 31 March, 1918, the capital expenditure for the factories was as follows :—

	£
G.C.F.1	391,951
G.C.F.2	231,350[1]
G.C.F.3	289,790
G.C.F.4	284,266
	£1,197,357

In spite of additional expenses, the total was therefore within the amount of the Treasury sanction of £1,539,000, which included the construction of G.C.F.2 at Woolwich, as well as the land, buildings and plant for the other three factories. Construction and architects' fees for G.C.F.1 and G.C.F.3 were estimated at the beginning of 1918 as £21,700 and £14,880 respectively; the actual amount paid to Eley Brothers for these services was £14,562.[2]

X. Manufacture of 7·62 mm. in 1917.

Theoretically, the cups for cases and bullet envelopes were to be supplied to the Government Cartridge Factories by the Government Rolling Mills. In practice, however, sufficient supplies did not come forward to keep the factories going at first, and in December, 1916, both G.C.F.'s 1 and 3 were held up by the absence of cups. This was partly due in the case of G.C.F.1 to the delay on the part of the managing firm in submitting a design from which they could make the Russian cartridge case and which the Rolling Mills could also make on their existing machines. It was also due to the shortage of copper at the Mills and to the fact that they were experimenting in the direction of producing a standard cup for Russian ammunition. When they achieved a successful cup (Mark IV), supplies improved considerably. To supplement their deliveries the Government Cartridge Factories used the King's Norton cup, which they seem to have preferred also on the ground of superiority in manufacture. While they all agreed that the quality of the metal in the cups supplied by the Rolling Mills was satisfactory, they were equally unanimous as to the defects in their manufacture.[3]

In October, 1916, it was stated by Deputy Director-General (E) that all the factories should be in a position to commence output before the end of the year.[4] This estimate proved to be too sanguine, especially in the case of G.C.F.4, whose machinery was only being installed in February, 1917. G.C.F.1, however, began operations in both case and bullet shops before Christmas, 1916. Deliveries were

[1] This was at 31 December, 1917; the March figures for G.C.F.2 are not available.
[2] C.R./2913. D.D.G.E./EM2/1218. P.C.7/13. Hist. Rec./H/1122/83.
[3] D.D.G.E./EM2/529.
[4] *Ibid.*

delayed by the difficulty experienced in making a satisfactory bullet and by the backward condition of the loading shops. In March, 1917, Messrs. Kynoch came to the rescue with a supply of bullets and deliveries for the month totalling 4,175,000. This was, however, disappointing when compared with an estimate of 10,500,000 for the month framed in January, 1917. Bullet manufacture improved gradually, but in the later months of the year difficulties developed in the necking process of the case, with the result that in October bullets were ahead of cases by 5,000,000 or 6,000,000. The effect of these difficulties in manufacture was that output rose but slowly. It was estimated that the full output of 6,000,000 weekly should be attained in October, but deliveries did not reach 5,000,000 at this date. In November, however, the output averaged 6,176,500 weekly. This was the highest output attained while the factory was making 7·62 mm.[1]

The output from G.C.F.3 came near to expectation. It was estimated that the output for June would be 2,500,000, and the actual attainment was nearly 2,000,000. This was considered a very satisfactory start, especially as there were no rejections by the Inspection Department from the first large delivery. Though starting operations considerably later than G.C.F.1, the factory attained its full output much more quickly. By 10 October it was producing 3,000,000 weekly, working on a day shift only, and Major Dixon reported "this is the first G.C.F. to reach the output asked for, and the result is largely due to the energy and resource of Mr. Needham, the manager."[2]

G.C.F.4 was very disappointing as regards its output. Though production was stated to have begun on 1 May, 1917,[3] on 1 August no deliveries had been made from the new factory, the small output of 7·62 mm. given by the firm being obtained entirely from the old works. In October it was again reported that "none of the processes on Eley Brothers' cartridges were being performed at G.C.F.4." The highest output of 7·62 mm. attained by the combined production of the old and new works appears to have been an average of 1,788,000 weekly in December, 1917, as against a full output of 3,000,000 weekly.[4]

The cost records for 7·62 mm. which exist are only continuous over any period of time for G.C.F.1. This factory gave records from September, 1917, to March, 1918. For G.C.F.3 the costs for October and November are given, and for G.C.F.4 for November and January, No fair comparison can, however, be made, because the factories started production at different dates, and they did not all include the same items in their costs. G.C.F.1 allowed a reserve for carriage in their total, which G.C.F. 3 and 4 omitted. G.C.F.4 did not deduct from their total any credit for scrap recoverable from Woolwich rejections, while the other factories took this into account in estimating

[1] D.D.G.E./E.M.2/529.
[2] *Ibid.*
[3] D.D.G.E./EM2/1363.
[4] D.D.G.E./EM2/529.

their net costs. The costs as stated by the different managements are as follows :—

	G.C.F.1.	G.C.F.3.	G.C.F.4.
September, 1917	136/3	—	—
October, 1917	130/10	117/11	—
November, 1917	127/-	115/11	143/10
December, 1917	125/4	—	—
January, 1918	119/7	—	152/9

The costs of G.C.F.1 for February and March are given over periods of a fortnight and six weeks and are therefore omitted. The high costs of G.C.F.4 in January are explained by the fact that the manufacture of 7·62 mm. was being reduced preparatory to closing down the factory.[1]

XI. Manufacture of ·303 in. in 1918.

The change in output of G.C.F.'s 1 and 3 was consequent on the decision of the Minister that no more ammunition was to be manufactured for Russia, and upon the revision of the small arms ammunition programme in December, 1917. It was arranged that both factories should produce ·303 in. Mark VII Z, *i.e.*, with a nitro-cellulose instead of a cordite filling. During the first three months of 1918 the factories were working off their last deliveries of 7·62 mm. and beginning delivery of ·303 in. G.C.F.3 gave a delivery of 7,500,000 during January, and in February exceeded its estimated output of 14,000,000. G.C.F.1 did not begin ·303 in. output till April, but then its deliveries far exceeded estimates. Throughout the critical months of the German offensive both factories steadily increased their output, that of G.C.F.3 being almost invariably above the estimate of its production given by E.M. 2.[2] This was attained by the working of double shifts, by the sacrificing of the Easter and Whitsuntide holidays, and by the relaxation of the Home Office restrictions on Saturday and Sunday work during April and May.

Costs of manufacture of ·303 in., inclusive of management fee, are given by G.C.F.1 as follows [3] :—

May, 1918	114s. 11d. per 1,000.
July, 1918	111s. 10d. „
September, 1918	113s. 2d. „

G.C.F.3's returns are given over a period of six months. From March to September, 1918, they were 115s. 7d., and from September, 1918, to March, 1919, 120s. 7d. The high cost of the later period is accounted for by the small production of the factory after the Armistice.[4]

[1] Figures given by Costs Statistics Department.
[2] See Appendix II.
[3] D.D.G.E./EM2/1519.
[4] Figures supplied by Factory Accounts Department.

XII. Comparison of Efficiency.

The difference in output between the factories bears a direct relation to the comparative efficiency of the managing firms. The organisation of G.C.F.3 was certainly the best. The manager appears to have been a thoroughly capable man, with a gift for choosing the right people for the work. There seem to have been comparatively few changes in the staff, and the steady rise in output when once production started implies careful organisation by the management and hearty co-operation on the part of the employees. The quality of the cartridge turned out was also good; in December Major Dixon reported that G.C.F.3's 7·62 mm. bullets were "some of the best in the trade." The activities of the management were not confined entirely to turning out cartridges: it is on record that the factory was at one time the proud possessor of 23 flourishing pigs, "minus one, now dead."[1]

G.C.F.1 suffered considerably from the breakdown in health of the first manager and the consequent over-pressure on his assistant But, even when allowance is made for this, the organisation does not seem to have been good; the staff was constantly changed, and the large percentage of scrap produced in the course of manufacture tells its own tale. In July, 1917, it was 20 per cent. in the case shop as against 5 per cent. in G.C.F.3. Rejections on inspection were also unduly large in 1918, amounting to 10 per cent. at one point. Another difficulty that G.C.F.1 had to struggle against was the insistence of the Birmingham Metal and Munitions Company that all correspondence and all purchase of stores should be dealt with through their own organisation at Adderley Park, and though the Government Cartridge Factory management was constantly pointing out the delays and difficulties resulting from this practice, the firm declined to alter it.[2]

The organisation at G.C.F.4 does not appear to have been good, and in addition the Ministry did not approve of the type of machinery installed for some of the operations, saying that it was "not in accordance with present-day methods of manufacture." It was pointed out, however, that the views of small arms ammunition manufacturers differ enormously as regards machinery, and that the fault lay rather in the way the machines were used. Poor organisation was reflected in the small output attained by the firm, though the quality seems to have been fairly satisfactory, the figure of merit on bullets being in December, 1917, equal to that of Messrs. Kynoch and Greenwood & Batley.[3]

XIII. Labour.

"These new G.C.F.'s ought to be models of what should be done in the way of using the smallest possible quantity of trained labour, and making use of women's labour." A report on dilution of labour in small arms ammunition factories issued in June, 1918, shows how

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[1] D.D.G.E./EM2/529. [2] *Ibid.* HIST. REC./H/1122/83. [3] D.D.G.E./EM2/529.

far this declared policy of the Ministry was carried out. Dilution was carried out to its fullest extent in G.C.F.3, where only 4 per cent. of skilled men were employed throughout the whole works, and the number of women and boys reached 82 per cent. In the tool room 78 per cent. of the work was done by women and boys, who were engaged on all operations necessary for the making and hardening of punches and dies. In the case and bullet shops all operations were performed by women, who also did a good deal of the tool-setting. In G.C.F.'s 1 and 4 the proportion of skilled labour employed in the whole works was larger, being 10 per cent. and 14 per cent. respectively. This, however, was better than the attainment of any trade firm, the best achievement in this direction being 16 per cent. of skilled labour (attained by the Birmingham Metal and Munitions Company and the King's Norton Company, the two firms managing G.C.F.'s 1 and 3). Dilution in the tool-room of G.C.F.1 was not as good as G.C.F.3, 63 per cent. only of the employees being women and boys.[1] The management of G.C.F.4 was hampered in diluting labour in the tool-room by the agreement made by Messrs. Eley with the Amalgamated Society of Engineers, that women should only be employed in that department on repetition work. In relation to the trade, it should be remembered that the Government Cartridge Factories were working under much better conditions of buildings and machinery, and therefore were able to dilute more easily. Moreover, they had the advantage of having trained their own workpeople. Owing to this training scheme, the factories had comparatively little difficulty as regards labour, though G.C.F.3 had some trouble at the beginning through lack of skilled labour, especially in the tool-room, and through the dislike of the skilled tool-room hands to women working with them. In April, 1918, also, the factory found great difficulty in getting labour to meet the great increase demanded in production.[2]

XIV. Closing Down.

As G.C.F.4 had been taken over by the Air Board on 1 April, 1918, and G.C.F.2 had become an integral part of the Woolwich small arms ammunition shops under the name of C.F.6, only two of the original four factories remained to be dealt with when the Armistice was signed. Three months' notice was given to them to close down, and instructions were issued that no more virgin copper, spelter or nickel should be used. A gradual decrease in output took place. Production of new ammunition ceased entirely in G.C.F.1 by the end of the year, but G.C.F.3 continued to produce on a small scale in 1919. G.C.F.1 was taken over by the Central Stores Department for storage purposes. The ultimate disposal of the factories presented some difficulty owing to the rights over them given to the managing firms in the original agreements. If the Government took them over entirely as National Factories, the firms would probably

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[1] (Printed) *Weekly Report*, No. 148, IX (29 June, 1918).
[2] D.D.G.E./EM2/529. Hist. Rec./H/1122/83.

demand considerable compensation for waiving their rights of management. On the other hand, small arms ammunition factories were not easily adaptable for peace time industry, and if the Ministry sought to dispose of them, the option of the managing firms to purchase at a lower price had to be considered.[1] In September, 1919, negotiations were in progress for the sale of G.C.F.1. G.C.F.3 was closed and included among those factories which were to be permanently retained or disposed of subject to satisfactory conditions as to reinstatement and storage of the plant.[2]

[1] D.D.G.E./EM2/1891.
[2] (Printed) *Weekly Report*, No. 209 I (6 September, 1919).

CHAPTER VIII.

SUPPLY OF CARTRIDGE METAL STRIP.

I. Early Arrangements for Supply.

The history of the supply of the raw materials required for the production of small arms ammunition belongs to the history of the control of materials rather than to that of small arms ammunition manufacture. Supplies of strip are on rather a different footing, as both brass and cupro-nickel strip are semi-manufactured materials used very largely by small arms ammunition makers, and therefore the provision of adequate supplies was a matter of which the Small Arms Ammunition Department was bound to take cognisance.

At first, small arms ammunition makers made their own arrangements for supply without any reference either to the War Office or to the Ministry. The bigger firms had their own casting and rolling mills, and arranged contracts for the supplies of copper, spelter, and nickel necessary to make their strip. But as their output increased, these firms found their rolling facilities insufficient, and supplemented their own production by contracts with strip manufacturers. Firms with no rolling mills were obliged to rely entirely on strip manufacturers. These were for the most part located in Birmingham and belonged to the Birmingham Cold Rolled Brass Association. Many of them were firms who had only recently taken up the work, and their output, which they divided among their different customers, was comparatively small. The result was that an ammunition maker with a large output had to get his supplies of strip from a number of sources, with the resulting disadvantages of variation in quality, uncertainty of delivery, extravagance and waste of labour. As an example, we may take the case of Woolwich. In March, 1916, besides the output of their own casting and rolling mills, the cartridge factories were obtaining their strip supplies from 21 different firms, in amounts varying from 1 to 26 tons a week.

The difficulties experienced by firms in obtaining supplies caused them to appeal to the Ministry for assistance, and the matter drifted into the hands of the Raw Materials Department. At the beginning of 1916 this department was arranging supplies of brass strip for the Ordnance Factory, Kynoch, and Eley Brothers, and of cupro-nickel strip for Rudge-Whitworth. But, as they pointed out, their work was really to supply raw materials only, and they had neither the technical knowledge nor the staff necessary for supervising the supply of a manufactured material.[1]

[1] Memo. by Mr. A. Duckham (C.R./4501).

II. Supply by the Small Arms Ammunition Department.

Matters were in this unsatisfactory state when the increased programme of small arms ammunition, sanctioned by the Minister in February, 1916, caused the Supply Department to institute a searching inquiry into the position of strip supplies. This brought to light some disquieting facts. The rejections of ·303 in. ammunition, which at this date were considerable, had, in the case of two makers, the Royal Laboratory and Messrs. Eley Brothers, been traced to bad brass, while Messrs. Kynoch, Ltd., and Greenwood & Batley were suspicious of the quality of their brass. The faulty strip was due in part to the poor quality of the materials used by some of the makers, who obtained their own materials instead of applying to the Ministry for them, and in part to bad methods of manufacture, the inevitable result of the casting and rolling processes being undertaken by a number of small firms with no proper facilities for manufacture. As regards cupro-nickel strip, while the quality was satisfactory, the quantity was limited. It was doubtful whether the output would even cover the contracts for the 400,000,000 rounds of the old programme, and there was no hope of obtaining supplies from the existing plant to cover the increased output under the new programme.

The Ministry therefore decided that new and reliable sources of supply must be found for both brass and cupro-nickel strip. There was some discussion as to whether the Raw Materials Department or the Small Arms Ammunition Department should take up the matter, and eventually it was decided that, while the Raw Materials Department should continue to look after any supplies of strip which they had undertaken in order to assist firms manufacturing small arms ammunition under the old programme, the Small Arms Ammunition Department should be entirely responsible for the supply of strip for the increased output under the new programme. The Raw Materials Department would, however, provide the metals required for this strip upon the requisition of the Small Arms Ammunition Department.[1] It was soon found, however, that this division of responsibility was not satisfactory, and the supply of strip was taken over entirely by the Small Arms Ammunition Department.

III. Establishment of the Government Rolling Mills.

There were two possible means of increasing the existing strip supply. Large extensions might be made to existing plants, or a central factory might be established under Government control. Mr. Alexander Duckham favoured the latter plan, and on 3 March he asked for authority to prepare a scheme for establishing, at the expense of the Government, a casting and rolling factory, designed for a capacity sufficient to meet the demands under the new programme.

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[1] Memo. by Mr. A. Duckham (C.R./4501).

(a) Advantages of the Scheme.

The advantages of the scheme were as follows:—

(1) A central factory would meet the increased demands much more effectually than extensions of existing plant, and would also avoid the difficulties caused by the inferior and varying quality of the strip produced by small makers.

(2) If a cupping plant were included in its equipment transport and depreciation by dirt of the scrap (which amounted to some 40 per cent. of the total metal) would be saved.

(3) The new proposal would effect great economy in labour and, if erected in a suitable locality, the factory could draw on the large reserve of unskilled labour, which, with a short training, would be quite suitable for casting and rolling.

(4) It was hoped that the factory would have a surplus capacity for both kinds of strip and for cupping, and thus, when giving its full output, it could supply part of the requirements under the old programme.

(5) On the estimated cost of the factory (£600,000 to £700,000) the saving in one year on current prices would amount to £1,500,000.

(6) The new factory would be, after the war, a saleable commercial undertaking, which would compete with the most up-to-date German factories for the export trade which had been, in the past, practically a German monopoly.

The Minister approved this proposal, and, in view of the "great urgency" of the matter, Mr. Duckham was requested to take "immediate and energetic action" to obtain an output as early as possible.[1]

(b) The Site of the Mills.

In choosing Southampton as a suitable place for the erection of the Rolling Mills, the Ministry was actuated largely by transport considerations. It was hoped that great economy would be effected in the railway freight of material, since Southampton was the delivery port of much of the raw metal, and of coal, oil, and other stores, which could be brought by water at one-third of the cost of railway transport. As for every 30,000 tons of raw material and fuel used, only 4,000 to 5,000 tons of strip are produced, this was a consideration of no small importance, and it was thought that on carriage costs alone the factory would be able to undersell Birmingham after the war by fully £1 a ton. A southern port was also eminently suitable if the factory was to compete with Germany for the export trade. Other reasons for the choice were that Southampton was fairly safe from Zeppelin and naval attacks, there was an ample supply of water available, and the type of labour required was comparatively plentiful.[2]

The site actually selected was on the Weston Grove estate at the junction of the river Itchen with Southampton Water. Thus there was excellent access by water, while railway access could easily be

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[1] Memo. by Mr. A. Duckham (C.R./4501).
[2] *Ibid.*

obtained by constructing a branch line to the London and South-Western Railway which ran less than a mile to the north-east. The ground was good, a point of special importance in a rolling mill. Water for condensing purposes could be obtained from the Itchen; there was a stream running through the property which would supply all the water required for the boilers; and the local water supply would be available for drinking purposes.[1]

The whole of the land belonged originally to Mr. Tankerville Chamberlayne, the owner of Weston Grove, but he had sold part of it to the London and South-Western Railway Company for their new dock scheme. It was taken over under the Defence of the Realm Act in April, 1916, in order that the construction of the factory might not be delayed until the negotiations for purchase were completed. The amount required from the Railway Company was approximately 29 acres, and a price of £650 per acre was ultimately fixed. The Ministry undertook the construction of a new road on the northern boundary of the land as a substitute for the existing shore road which was to be closed. Railway communication could be effected at Woolston Station, half a mile away.[2]

The negotiations with Mr. Chamberlayne were far less amicable. The land in question was the park of a large house, and the Ministry wished to acquire the house for the technical staff of the factory as well as a good deal of the park for the erection of the buildings and the construction of the new road. In order to secure a free supply of water from a pond lying some distance to the north-east of the factory, they also proposed to buy the strip of land forming the banks of the stream running out of the pond. Mr. Chamberlayne intensely resented the occupation of his property under the Defence of the Realm Act, and when, after lengthy negotiations, the Ministry refused to pay the exorbitant price that he demanded for it, he brought an action against them in the Court of the Railway and Canal Commission early in 1918. The verdict was given for the Ministry on the ground that the acquisition of the property came under Section 13 (1) *b* of the Defence of the Realm (Acquisition of Land) Act of December, 1916. Against this Mr. Chamberlayne appealed, but the decision of the Railway and Canal Commission was upheld, and further arbitration was then necessary to decide the price to be paid for the land.[3] This case was the first of its kind, and was therefore in the nature of a test case.

(*c*) CONSTRUCTION OF THE FACTORY.

The construction of the factory was begun early in May, 1916, and it was hoped that the buildings would be sufficiently advanced to start production by the end of 1916. Owing chiefly to the difficulty of obtaining labour this hope was not realised. In December, 1916, the cupping shop was only partly erected and the last warehouse had

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[1] Memo. by Mr. A. Duckham (C.R./4501).

[2] 94/Nat./140.

[3] C.R.V./Gen./2067. Apparently this was about £31,000, since the total estimated expenditure for the land was £50,000, and £19,000 approximately was paid to the London & South Western Railway Company.

progressed no further than the foundations. The rest of the buildings were, however, sufficiently advanced for machinery to be running and one part of the cupping shop was being used. The factory was finished about September, 1917.[1]

The primary consideration in designing the Rolling Mills was rapid and economical production, which was ensured by a continuous system of work throughout the factory. On one side the whole of the brass output was dealt with, and on the other cupro-nickel bullet and cap strip were produced. A railway track and overhead gantry connected the pier with the first warehouse, in which the raw materials were prepared for melting. In the foundry these materials, consisting of nickel, copper, and spelter, were cast into ingots and then passed into the second warehouse. Here they were cropped and sorted before going to the rolling mills, where the finished cartridge metal was produced. In the third warehouse the strip was weighed, sorted and tested, and in the last shop it was made into cups. Special features of the machinery were the gas-fired melting furnaces, which were capable of dealing with much larger heats than usual, and the arrangements of the rolling mills, each of which did one pass only, so that the metal was never moved backwards. This scheme of work reduced labour to a minimum, and ensured the quickest possible production, since all unnecessary handling of the material was eliminated, and the possibilities of congestion were considerably lessened.

The power station was situated close to the pier, because it was assumed that most of the fuel would be brought by water. A gas works was attached to the power house, as the quantity required for melting and annealing was more than could be supplied by the local gas company.

The second point kept in view in the design of the factory was its use after the war. It was hoped that it would turn out nickel, copper and zinc alloys, which would be supplied in the form of ingots, plates, sheets, strips and ribbons, rods, wires, tubes and castings. The plant for plates and strips was already provided, but additions would be required for the other processes as well as for the heavier plate work. In designing the factory ample room was therefore left for additional plant, and as, after the war, the output of cartridge cups would be considerably reduced, further space would be available in the cupping shop. The additional machinery required would include tube and wire mills and a sand plant for castings, as well as rolling mills for bars and rods. The estimated cost of the additions and alterations was approximately £100,000, and the result would be a self-contained factory capable of dealing with all the requirements of the non-ferrous metal trade.

(*d*) Output.

Under the original scheme the factory was to produce cups for the new Government Cartridge Factories. It was estimated that its output, working day and night shifts, would be 1,000 tons of cupro-nickel strip and 3,750 tons of brass strip per month. This would

[1] C.R.V./C/2067.

produce 42,000,000 brass and 42,000,000 cupro-nickel cups per week, an output at least four times greater than that of any other British rolling mill, and about equal to the most modern German rolling mills. In actual practice the factory never produced anything like this total amount, since the decreased output of the Government Cartridge Factories arranged in January, 1917, involved a corresponding reduction in requirements for cups. The rate of output, however, for the day shift only, exceeded the estimated figures.

Its maximum production in any one week was 662 tons of brass strip (S.A.A. and Q.F.) and 91 tons of cupro-nickel strip, while its largest weekly output of brass cups was approximately 24,000,000 and of cupro-nickel cups 19,250,000. Though it was hoped that the factory would start production on a small scale in October, 1916, it actually began cupping operations in November, 1916, rolling operations on 30 January, 1917, and casting on 7 February, 1917.[1] It must be remembered that, before starting casting and rolling, the equipment of the power house and gas works had to be completed, and it reflects great credit on those concerned that a supply of gas and electricity was available within nine months from the beginning of the work.

The reduction in the output of cups was to some extent compensated for by the extension of the activities of the factory to fuse stampings and Q.F. strip. In September, 1916, a scheme was put forward for the utilisation of the spare capacity of the Mills in producing 2,000 tons of fuse stampings and 2,000 tons of Q.F. strip per month. This scheme was approved by the Minister, and sanction was given for the additional machinery required in October.[2]

(e) Cost of Erection and Equipment.

The original estimate for the erection and equipment of the factory was £673,956 exclusive of the cost of the site,[3] and financial sanction was given for £680,000.[4] Owing to the additional plant required for the production of Q.F. strip and fuse stampings the actual cost considerably exceeded this amount. At the end of December, 1917, the total expenditure was estimated at £1,200,000, and this amount was not exceeded.[5]

(f) Cost of Production.

When the scheme for the Rolling Mills was set on foot, it was expected that considerable economy would be effected as the factory would be able to produce more cheaply than the trade. This expectation was not, however, realised, owing largely to the decreased output. As the mills were constructed as a single unit, economical manufacture could only be expected if they were employed to their full extent. When the cost of casting and rolling brass S.A.A. and

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[1] Minute for discussion of supply of strip at meeting of Munitions Council, 22 March, 1918 (W. 470).
[2] C.R./4438.
[3] Mr. McCall's Report to E.M.2.
[4] Minute for Munitions Council (W. 470).
[5] C.R./2913.

Q.F. strip was calculated for November and December, 1917, it was found that the cost for supervision, labour and fuel averaged £18 per ton, whereas the gross price paid to the trade for converting ingots into strip was £17 per ton. This price covered interest, depreciation, and profit to the firms, whereas none of these were included in the Rolling Mills costs. For the 18 weeks ending January, 1918, the cost of producing cupro-nickel strip was £60 5s. per ton compared with the trade price of £40 to £45. These prices were admitted by the management of the Rolling Mills to be high, but it was hoped that when the factory was in full working considerable reduction could be effected, even on the reduced output. As a set off against the high price, the quality of the strip produced was remarkably good, and the Supply Department considered that the Rolling Mills produced a better strip than any firm in the trade.[1] During 1918 costs were considerably reduced by a diminution in the loss of material during the manufacturing processes, the use of labour saving devices on the furnaces, and the introduction of a bonus on output in the mill and the cupping shop. Brass strip costs were reduced to between £11 and £12 per ton and cupro-nickel strip costs to under £35 per ton before the Armistice was declared. These figures compared very favourably with the Birmingham costs at the same date, and the excellent quality of the material produced by the mills enabled the Government Cartridge Factories to obtain a higher efficiency from Government Rolling Mill cups than from the average cups supplied by the trade.[2]

IV. Question of Closing Down the Rolling Mills, March, 1918.

In the spring of 1918 the question of closing down the Rolling Mills was discussed by the Munitions Council. The large cut in the programme of small arms ammunition manufacture arranged at the end of 1917 meant that the demand for brass strip would only be sufficient to occupy one third of the total capacity in the country. Under these circumstances it was a question of policy whether it would be better to shut down the Rolling Mills and allow the Government Cartridge Factories still in working to get their strip from the trade, or to keep the Rolling Mills producing sufficient strip to supply the two Government Cartridge Factories and to allow the principle of natural selection to operate in the trade to eliminate the least efficient producers. Against keeping the Rolling Mills in working, it was urged that Government production was only justified by the absence of a sufficient output or by a much reduced cost, neither of which factors were operating in this particular case. Moreover, there would be great resentment felt by the trade if Government activity were continued at its expense, and the unemployment resulting from decreased output in the Birmingham district would have a bad effect on labour. In answer to these weighty arguments there could only be urged the excellent quality of the Government Rolling Mills' output. It was generally felt that this alone was not enough to warrant keeping the mills going, especially as they might be transferred to other work.[3] The decision

[1] W. 470.
[2] Figures supplied by Director of Government Rolling Mills.
[3] W. 470.

to close the mills had practically been taken, when the March offensive altered the whole position. The demands for strip to meet the greatly increased small arms ammunition output more than occupied the capacity of the trade, and the Rolling Mills were required to supply the residue. This did not, however, utilise the full capacity of the mills, and parts of them were therefore used for the storage of seaplane hulls and 18-pdr. gun carriages.[1] As production of small arms ammunition slackened once more, the question came again to the front, but the signing of the Armistice made a decision on the specific issue unnecessary.

V. Disposal of the Mills after the Armistice.

Various proposals were put forward for the post-war use of the mills. The most ambitious suggestion was that they should be turned into a complete National Small Arms Factory on a similar footing to Woolwich and Enfield. Smaller suggestions were that they should be used as a storage centre for Government property, for manufacturing telephone and telegraph cable, or for melting down non-ferrous scrap in order that it might be disposed of in a more profitable form. All these suggestions involved their retention as Government property, a course which was urged on account of the high cost of the buildings, owing to war conditions and the impossibility of realising their value if they were sold in the near future. There were, however, insuperable objections to all these schemes, and eventually it was decided to dispose of the factory as a unit, and to utilise it for melting down brass scrap pending its purchase. It was put on the market early in 1919.[2]

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[1] D.D.G.E./E.M.6/437. C.G.M./2011.
[2] M/Demob./68.

CHAPTER IX.

FINANCE.

I. Rise in Prices in August and September, 1914.

The financial aspect of supply was vitally affected by the outbreak of war. The existing method of placing contracts on competitive tenders rapidly became impracticable. It was impossible to wait for the tenders before giving firms instructions to proceed with arrangements for manufacture, and in the chaotic conditions existing manufacturers quoted enormously high prices in order to cover themselves from the risks involved. The great increase in the demand necessitated large extensions of manufacturers' works, and most of the firms could not afford to take the risks involved in such heavy capital outlay, even if they had the capital to do so. The result was that the War Office was quite early forced to revolutionise its methods of dealing with firms, placing orders first on tentative terms and making formal agreements with contractors afterwards. Advances for buildings, plant and materials became a *sine qua non*, and the result was the growth of a complicated financial system in which practically every firm was given individual consideration.[1]

The prices under the contracts placed in May, 1914, by the Army Contracts Department on the old competitive system were as follows :—

Birmingham Metal and Munitions Company	103s. 0d. per 1,000.
King's Norton Company	101s. 4d. ,,
Kynoch, Ltd.	99s. 3d. ,,
Greenwood & Batley	99s. 0s. ,,
Eley Brothers	91s. 6d. ,,

Under the contracts placed in August and October, 1914, there was an average rise of 9·5 per cent. and 26·5 per cent. respectively on the pre-war contracts. The actual prices paid were as follows :—

Firm.	21 *August*, 1914. *s. d.*	*September*, 1914. *s. d.*
Birmingham Metal and Munitions Company }	108 6	—
Nobel's .. .. }	—	126 0
Greenwood & Batley	108 6	128 6
King's Norton Company	108 6	125 0
Eley Brothers	106 6	120 0
Kynoch	108 6	125 0

The prices named in the September negotiations were very high, and before placing the contracts the War Office attempted to obtain reductions. Except in the case of Greenwood & Batley and the King's Norton Company, whose original quotations were 129s. 6d. and 128s. 9d. respectively, they were not successful; and as Lord Kitchener had stated that the increased output was " too important

[1] 57/Gen. No./3595.

a matter for the question of expense to interfere," they had no option but to accept the manufacturers' terms. In order that the price should not constitute a precedent, they stated that it was given in order to recoup firms for their expenditure on additional plant, and that on further orders the price should revert to a lower level. A condition was attached to the contracts that the additional plant installed should be at the service of the Secretary of State for the duration of the war, and should not be dismantled after the war without a year's notice being given by the firm to the Secretary of State. A further condition stated that if the firms did not complete their order by contract date, the price of all cartridges delivered after that date should be paid for at the rate of 108s. 6d. only. The contractors unanimously objected to this penalty for non-delivery, and the War Office had to compromise. Either by letter or by a direct clause in the contract, all firms were given a fortnight's grace in which to complete deliveries, and were assured that no reduction would be made if they could show that the delay was due to causes beyond their control.[1]

The reasonableness of the manufacturers' position in this respect was shown when the contracts were due for completion. None of the firms were able to complete deliveries to time, and when asked to state the reasons for their failure, they all said it was due to the failure of building and machinery contractors to fulfil their promises and to the extreme difficulty of getting skilled labour. Under these circumstances, the War Office granted extensions of time to enable the contractors to complete their deliveries, and did not press for the payment of damages. It was felt that contractors were loyally doing their best under circumstances of considerable difficulty, and in view of the fact that further efforts on their part would be needed in the future, too rigid an insistence on financial penalties was simply killing the goose that laid the golden egg.

II. Advances for Extensions, Increased Equipment and Material.

In effect, the War Office bought the plant for the increased outputs under the October contracts, but capital advances were not made, except in the case of Messrs. Nobel, who received £27,600 for the erection of the new plant at their Waltham Abbey works.[2] But when further contracts had to be made, it became necessary to adopt the system of advances as a general policy. The outlay up to date had constituted a heavy drain on the capital of the companies, and even the largest firms were unwilling to undertake further responsibilities without financial assistance. From the beginning of 1915 nearly all contracts involving extensions or alterations, whether for increased output or for a change in manufacture, were arranged on the understanding that the Government would provide the necessary capital.

The agreements vary so much owing to the circumstances of individual firms that generalisation becomes difficult, but the principle

[1] 57/Gen. No./3595. [2] 15/Muns./86.

on which the War Office and the Ministry worked seems to have been to advance money to cover the estimated costs of the extensions on one of three conditions :—

(1) The condition already imposed in the September contracts, that the plant should remain at the disposal of the War Office for the duration of the war. This was inserted in the agreements of January and May, 1915, with the Birmingham Metal and Munitions Company, but after that date it was replaced by conditions more favourable to the Government.[1]

(2) Advances made for plant were to be repaid by instalments. This system was adopted in two cases only, the Rudge-Whitworth agreement of March, 1915, and the contract with Messrs. Eley arranged in May, 1915. Messrs. Rudge-Whitworth were to repay the £65,000 lent them by fixed sums calculated on the number of cartridges they were due to deliver by the dates on which the payments were to be made.[2] There were no fixed dates for repayment in the case of Eley Brothers; the firm was to repay the advance of £45,000 at the rate of 2s. 6d. per 1,000 accepted cartridges. As the contract was for 26,000,000 only, the advance would obviously not be repaid when it terminated, and it was therefore stipulated that on any further contracts instalments of 3s. 9d. per 1,000 should be repaid until the advance was fully paid off.[3]

(3) Advances made by the Government were not to be repaid, but the plant and machinery were to remain the property of the Government, though the contracting firm had an option to purchase them at the end of the war. If the advance was to pay for new buildings as well as plant, these remained the property of the firm, as they were generally extensions of existing works and built on land owned or leased by the firm. The earliest application of this principle seems to be the contract with Messrs. Kynoch in May, 1915, though the division of the property was differently arranged. This case is interesting because the firm proposed that the War Office should pay £184,000 for the erection and equipment of a new factory which was to be part of their Birmingham works, and the whole of which was to become their property. The War Office refused to agree to this one-sided arrangement, and eventually it was arranged that the War Office should retain the loading shops and plant, while the rest of the new shops with their plant were to become Kynoch's property.[4] This arrangement held good for the further advance of £183,700 negotiated by the War Office in July,[5] but when the Ministry took up the negotiations with the firm they were required to come into line with the general policy, and the advance in March, 1916, was given on the understanding that the plant should remain the property of the Government.[6]

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[1] Contracts/9101/A. 15/Muns./86.
[2] Contracts Firms R/2337.
[3] 94/C/51.
[4] 94/C/42.
[5] 94/C/364.
[6] 94/C/1810.

The contracts made by the Ministry with Eley Brothers form an exception to the rule. But in this case the Ministry was bound by the terms of the first agreement made with the firm, and therefore continued to place contracts on similar lines until the negotiations concerning G.C.F.4 provided an opportunity for getting the outstanding balance of the advance paid off, and left the way clear for bringing the firm into line with others.[1] Where they were bound by no previous agreements, as in the case of the advance of £75,000 made to Greenwood & Batley,[2] and of £14,500 to the Birmingham Metal and Munitions Company,[3] the Ministry applied the simple rule of keeping the plant as their property. The War Office period seems to have been one of experiment, of which the Ministry reaped the benefit and embodied the results in a settled policy.

Advances for material were not common; they only appear in two cases. In all contracts with Eley Brothers, until the arrangements for transferring all small arms ammunition manufacture to G.C.F.4 were made, an advance was provided for materials to be repaid by the deduction of a fixed sum per 1,000 accepted cartridges.[4] In Greenwood & Batley's ·303 in. contract made with the Ministry in May, 1916, £50,000 was advanced, to be repaid by the application of all payments due to the firm after notice of termination of contract had been given.[5]

III. Repayments of Advances.

Where advances were made without any provision for repayment, *i.e.*, in the cases of the Birmingham Metal and Munitions Company, Messrs. Kynoch, and Greenwood & Batley, the War Office and the Ministry attempted to safeguard themselves from failure on the part of the firms to deliver the cartridges by the insertion of a clause in the contract providing that if the firm failed to demonstrate its capacity to give the output agreed upon from the extension by a fixed date they were to refund a part of the advance proportionate to the difference between the estimated output and the actual output attained. They were successful in inserting this condition in Greenwood & Batley's agreements of May, 1916, and March, 1917.[6] The Birmingham Metal and Munitions Company also submitted to it in their contracts of January and May, 1915, but when the Ministry inserted it in the contract of May, 1916, the firm objected, and the Ministry conceded the point.[7] This was probably due to the fact that Messrs. Kynoch, with whom they were negotiating an increase at the same date, flatly refused to accept any such clause, saying that they hoped to get the output by the date stated, but they would not give any further guarantee. The Ministry had to accept the firm's terms, and no attempt was made to insert this clause in any other agreements with the firm.[8]

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[1] 94/C/990. 94/C/2081. 94/C/3323.
[2] 94/C/424.
[3] 94/C/1601.
[4] 94/C/51; /990; /2081; /3323.
[5] 94/C/424.
[6] 94/C/424; /3925.
[7] 94/C/1601.
[8] 94/C/1810.

In point of fact, the Ministry did not insist too rigorously on this condition being fulfilled. It was accompanied in the agreements by a clause stating that if the firm could prove *force majeure* a reasonable extension of time for delivery would be conceded before the clause was put into force. Where the firms failed to demonstrate their capacity, the reasons for delay were invariably given as failure of sub-contractors to fulfil their promises and shortage of labour, both of which causes were, as the firms concerned pleaded, outside their control. The case of the Birmingham Metal and Munitions Company is an excellent example of the policy of the Ministry. The firm were behind with their deliveries under their contracts of January and May, 1915, for the reasons quoted above. Under the first contract they were pledged to demonstrate their capacity by 28 June, 1915, but in October their output was only 3,000,000 instead of 5,000,000, and the Ministry granted an extension till January, 1916. The delay in this contract naturally threw their next contract behind. Their output of 4,000,000 weekly due under this contract by 27 November, 1915, had not been attained by February, 1916, and the Ministry again granted an extension of time to April. Even then the requisite capacity was not proved, so another extension was granted to August, 1916. By this date the firm had succeeded in attaining its requisite output and therefore retained the whole of the capital grant, a large part of which would have been forfeited had the Ministry insisted on the conditions of contract being strictly fulfilled.[1]

Similarly, where repayments for extensions were concerned, *e.g.*, in the case of Rudge-Whitworth, the Ministry extended the dates by which repayments were to be made if the firm could show reasonable cause for delay in delivery.[2] The general policy with regard to finance was the same as that adopted with regard to deliveries, and may be summed up in the words of Major Byrne. "Speaking generally, we think English firms should be treated reasonably, wherever possible, as regards payment for extension of plant. They made worse bargains than the American manufacturers and are acting up to their promises, which the Americans are not."[3]

IV. Changes in Type of Ammunition Manufactured.

With regard to the financial arrangements when firms changed the type of ammunition they were manufacturing, the Ministry adopted three principles :—

(1) Any new plant necessitated by the change was paid for by the Ministry, the plant remaining the property of the Government with the usual option of purchase by the firm. Alterations to existing plant owned by the firm were sometimes to be carried out at the firm's expense,[4] and sometimes at the expense of the Ministry.[5]

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[1] 15/Muns./86.
[2] D.D.G.E./EM2/49.
[3] 57/Gen. No./3595.
[4] 94/C/3731.
[5] 94/C/4278.

(2) Compensation was paid to the firms for any loss of output involved in the change over. This was reckoned at the rate of 10s. per 1,000 (which was approximately the profit which small arms ammunition manufacturers expected to make) on the difference between the actual output of the new type of cartridge being manufactured, and the output which the contractor was estimated to obtain had he continued to produce his old type. The compensation to Messrs. Greenwood & Batley in their change over from ·303 in. to 7·62 mm. amounted to £32,255 9s. 3d.,[1] that to Messrs. Kynoch for a similar change to £59,948 8s. 6d.[2]

(3) Where necessary, the Ministry also agreed to refund to the contractor the amount which had been paid by him in order to retain the services of skilled workpeople in the interval between the reduction of this old output and the working up to the full deliveries of the new type. This condition appears in Greenwood & Batley's contract for changing to 7·62 mm. at their Albion Works,[3] and the agreements with regard to changing to Roumanian cartridges and back to ·303 in. with the King's Norton Company.[4]

The only instances in which changes were not arranged on these lines are the contracts with Kynoch, Ltd., for changing to the manufacture of ·256 Japanese ammunition and with Messrs. Nobel for changing to 7·65 mm. where the firms paid the whole costs of the change themselves and the price of the cartridges was raised to cover the expense.[5]

V. Effect of Advances on Prices.

The variation in price between firms is considerable, but it is explained by the fact that the free action of competitive trading was hindered by the clauses of the agreements made with the different firms and by the capital advances made to them. Naturally the tendency was for prices to rise steadily owing to the increasing cost of materials and labour. This is clearly seen in cases where the Government placed a continuation contract, involving no extensions and no capital advances. Messrs. Greenwood & Batley's contract of October, 1914, was nearly completed in May, 1915, and the War Office therefore placed a further contract for 45,000,000. The firm quoted 136s. per 1,000 for this order, and when the War Office demurred, they stated that in spite of the increased price they would make 25 per cent. less profit than on the previous order. This appears to be the highest price ever given for ·303 in. Mark VII, but the firm were "expensive manufacturers."[6]

The King's Norton Company's price is another example of one which was unaffected by agreements. After the first extensions which the firm made to fulfil their promises under their September contract with the War Office, they did not increase their works any further, and their output remained at 4,000,000 to 4,500,000. A

[1] 94/C/3925.
[2] 94/C/4369.
[3] 94/C/3925.
[4] 94/C/4278. P.M./C/6174.
[5] 94/C/1637. 94/C/4711.
[6] 94/C/178.

running contract was placed with them to continue supply at this rate in May, 1915, and the price then arranged was the same as their previous contract, 125s. per 1,000. In spite of the rise in price of materials and labour, the firm continued to manufacture at this price till the end of 1917, when it was the lowest in existence.[1]

Such simple financial arrangements as this are comparatively rare. The position with most firms was complicated by two factors, the policy adopted early in 1915 of making running contracts instead of contracts for a fixed amount, and the limitations on price necessitated by the system of capital advances. The early policy of the War Office had been to make contracts for a definite quantity of cartridges. This enabled contractors to cover themselves for the total amount of materials they would require at the beginning of the contract, and therefore they could quote a fixed price for deliveries. But when the Government placed a running contract, it was no longer possible for the contractor to purchase his materials *en bloc*, and a system had to be devised whereby the price of cartridges would vary with the price of materials, so that the contractors' profit remained relatively the same.

The effect of the capital advances made to firms was obviously to bring the price of cartridges down. When the buildings and machinery for increased output were paid for by the Government, the firms had no longer to recoup themselves for capital outlay, and therefore the War Office insisted on a much lower price. But the fixing of a low price to start with meant that the firm was quickly affected by the increased cost of materials and labour, and a revision of prices was needed. A comparison between the King's Norton Metal Company and the Birmingham Metal and Munitions Company brings out this point clearly. The former, starting in 1915 with a fixed price of 125s. per 1,000, were able to continue for two years at the same price; the latter, starting in January, 1915, with their pre-war price of 103s. per 1,000 (they had a capital advance of £140,000), had to change on their new contract in May to 110s. per 1,000, in spite of another capital advance of £150,000, and they stated that even then they would make less profit than on their previous contract, so greatly had costs increased since the beginning of the war.[2]

Another factor complicating the position was that in some cases the Government made it a condition of a capital advance that they should have the option of placing further orders at the same price when the contract under negotiation was completed.[3] Thus, the usual course of revising prices at the beginning of a new contract was barred out, yet obviously if the price remained stationary for long, it would cease to bear any reasonable relation to costs of material and labour. Messrs. Kynoch were faced with this difficulty in the contract which they made with the War Office in May, 1915. In view of the large advance made to them and of the fact that so much

[1] 94/C/245. [2] 15/Contracts/36. [3] 94/C/51. 15/Contracts/36.

of the extension was to remain their property, the War Office considered that they should get a *quid pro quo* in the shape of a cheap supply, and therefore suggested that the price settled under this contract should apply to all future orders placed with the firm. In order to meet the views of the War Office, and yet to safeguard themselves from loss, the firm suggested the expedient which developed under the Ministry into a settled policy—the "sliding scale." It was arranged that a basis price of 100s. per 1,000 for the first 100,000,000, and 95s. per 1,000 for any excess over this amount should be fixed. But this price was to be subject to variation corresponding to the change in the price of materials as follows :—

For every £1 per ton in the price of lead above or below £18 10s., the price per 1,000 cartridges should be increased or decreased 2·4d.

For every £1 per ton in the price of nickel above or below £175 per ton, the price per 1,000 cartridges should be increased or decreased ·65d.

For every £1 per ton in the price of cartridge metal above or below £69, the price per 1,000 cartridges should be increased or decreased 2·67d.

For every 1d. per lb. in the price of cordite above or below 3s. 2d., the price per 1,000 cartridges should be increased or decreased 5·25d.[1]

VI. Sliding Scales to meet Increased Cost of Material.

This expedient of the sliding scale proved the solution for the problems raised by the introduction of running contracts and the system of capital advances. It was therefore adopted and developed by the Ministry. From May, 1915, onwards the use of the basis price and sliding scale became general. In a few instances fixed prices were still arranged, *e.g.*, Messrs. Kynoch's contract for ·256 in. Japanese ammunition was arranged at a fixed price of 131s. 4d. per 1,000,[2] and small orders for special ammunition were sometimes placed at a fixed price. But where the contract was a large one, placed under special conditions, or where the costs of production could only be ascertained by experience, the flexibility of the sliding scale method made it the fairest way of settling price, and ensuring that a firm should not lose unduly through the unusual conditions of the market nor the Government have to pay exorbitant prices.

The scale as suggested by Messrs. Kynoch was only tentative, and experience of it in working soon showed that it was "inaccurate and muddled."[3] Accordingly, when the Government began negotiations for a new contract, the firm themselves suggested alterations which were acceded to by the War Office. This change is typical of the history of the sliding scale. It needed many variations and many additions before it could be used as a general framework. It was not till the middle of 1916 that it appeared in anything like a complete form. Greenwood & Batley's agreement of May, 1916,

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[1] 94/C/43. [2] 94/C/505. [3] *Ibid.*

showed it in an intermediate form. In this contract it included variants for cupro-nickel strip, cartridge metal strip, lead rod, percussion caps, cordite and aluminium wire.[1] The scale inserted in the agreements with the Government Cartridge Factories[2] was a more complete form, and seems to represent the final evolution, as it appeared again in contracts placed with Rudge-Whitworth and with the Birmingham Metal and Munitions Company in March and June, 1917.[3]

As the variant in the sliding scale was based upon the weights of metal used, it was fixed for each type of ammunition,[4] but the basis price of cartridges and the standard price of materials on which the variation was to be calculated varied with the date at which the agreement was made. The basis price bore a rough relation to the prices of materials ruling at the date of the contract. Basis prices in the early part of 1916 ranged from 95s. to 108s. 6d. In November, 1916, a contract was placed with Rudge-Whitworth at 133s. 3d. per 1,000 and in March, 1917 at 133s. 7d.[5] But the relation between prices and cost of materials did not always hold good, as in June, 1917 the Birmingham Metal and Munitions Company took a contract at 101s. 6d.[6] But if a low basis price was arranged it was accompanied by a low standard price. Thus the Birmingham Metal and Munitions Company's standard prices for materials in 1917 were much lower than Rudge-Whitworth's, and the loss which they would have made on their basis price was balanced by the large difference between the standard price and the actual price of materials. But since, as a general rule, both basis prices and standard prices were directly related to the prices of material, a comparison of the standard prices at different dates gives some very interesting indications as to the growth of prices and material, and the consequent effect on the manufacture had no provision been made for variations. It is impossible to make a complete comparison, as manufacturers had material supplied to them in different forms, *e.g.*, some firms had percussion caps supplied to them complete, others had the copper and the fulminate of mercury separately. But certain materials appear in all the schedules, and for these a comparison can be made. The schedule of Nobel's contract of April, 1916, gives the standard prices at that date, the Government Cartridge Factory schedules represent the standard prices for the autumn of 1916,[7] and the Rudge-Whitworth agreement those for March, 1917.

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[1] 94/C/424.
[2] See p. 53.
[3] 94/C/5087. P.M./C/5438.
[4] For variants for ·303 in. see p. 53.
[5] 94/Firms R/325. 94/C/5087.
[6] P.M./C/5438.
[7] Though the dates of the formal agreements are the spring of 1916, when the heads of agreements were signed, the formal agreements were not really complete till the middle of 1917 and were constantly being changed during 1916; the autumn of 1916 may be taken as an average date for the settling of schedules, etc.

Material.	April, 1916.[1]	Autumn, 1916.[2]	March, 1917.[3]
	£ s. d.	£ s. d.	£ s. d.
Brass strip ..	69 0 0 per ton	147 0 0 per ton	161 0 0 per ton
Cupro-nickel strip	120 0 0 ,,	185 0 0 ,,	202 0 0 ,,
Lead rod ..	18 10 0 ,,	32 10 0 ,,	36 15 0 ,,
Aluminium rod..	106 0 0 ,,	196 7 0 ,,	265 0 0 ,,
Cordite	3 2 per lb.	3 2 per lb.	3 2 per lb.

Conditions within individual firms also affected prices. Between April and July, 1916, contracts for ·303 in. Mark VII were placed with Messrs. Kynoch, the Birmingham Metal and Munitions Company, Greenwood & Batley, and Nobel. All except Messrs. Nobel had advances for extension, the prices and advances being as follows :—

Firm.	Price per 1,000.	Total Advances.	Total production per week.
	s. d.		
Kynoch	95 0	£368,000+money to be spent on extension	23,000,000
Birmingham Metal and Munitions Company.	96 6	£304,500	15,500,000
Greenwood & Batley	108 6	£75,000	8,000,000
Nobel's	105 0	£27,600	2,000,000

From this it appears that basis prices were dependent to some extent on the amount of the advances made to the firm and the total output of the firm. Greenwood & Batley's price was obviously high, but it was a recognised fact throughout that they were an expensive firm, and their prices always ranged higher than other firms. The prices of the remaining firms cannot be compared, as Eley Brothers and Rudge-Whitworth were both paying back advances, and therefore their basis prices were considerably higher on this account; and the King's Norton Company, with a fixed price and no advances, was on a different footing altogether.

VII. Wages and Scrap Variants.

While the problem of how to meet the rise in prices of materials was settled in 1915, the increased cost of labour was not dealt with till 1916. Obviously any large rise in wages would mean that the rate of profit on contracts was considerably decreased unless a provision similar to that regarding materials was inserted. In January, 1916, Eley Brothers wrote to the Ministry saying that between 1 February and 4 November, 1915, the costs of labour had increased by 2s. 7d. per 1,000 cartridges, and that in the new contract which was being negotiated with them they would like some provision made to meet

[1] 94/C/1423 [2] 94/C/1747. [3] 94/C/5087.

probable further increases. Accordingly a wages variant was inserted stating that " for every increase or reduction of 10 per cent. above or below 21s. 11·58d. per 1,000 cartridges for wages paid by the contractor to women workers, tool-makers, machine minders and labourers, the price of cartridges was to be advanced or reduced by 1·77 per cent. per 1,000 accepted cartridges."[1]

From this time a wages clause appeared in all contracts settled on basis price and sliding scale terms. In the contracts placed with the Birmingham Metal and Munitions Company and with Greenwood & Batley in May, 1916, variations of ⅜ per cent. and ¾ per cent. on the basis price were allowed to meet increases of 2½ per cent. and 5 per cent. respectively in the rate of wages.[2] Contractors who had running contracts next asked for the insertion of a wages clause in their contracts, and the Ministry therefore drafted a general clause to be inserted in future contracts as follows :—

> " If at any time during the continuance of this contract any variation is made in the rates of wages of any class of labour employed on the production of cartridges under this contract from the rates paid on the 26th April, 1916, and such variation is in accordance with—
>
> (*a*) An Arbitration under the Munitions of War Act, 1915, as amended by the Munitions of War (Amendment) Act, 1916.
>
> (*b*) An order of the Minister made under Section 6 or Section 7 of the Munitions of War (Amendment) Act, 1916.
>
> (*c*) An agreement which in the case of Controlled Establishments has been sanctioned by the Minister under Section 4 (2) of the Munitions of War Act, 1915, or, in the case of Uncontrolled Establishments, has received the support and assent of the Minister.
>
> (*d*) The provisions of the Fair Wages Clause in cases where the district rate of wages has been advanced subsequently to the 26th April, 1916.
>
> The price of the cartridges manufactured under the contract after the 12th December, 1916, shall be varied in accordance with the attached ' Rules for determining the effect of wage fluctuations on price.' "

In some contracts clauses relating to fluctuations in the price of scrap were inserted, but they were not general. In Eley Brothers' contracts of February and June, 1916, a variant of ·83d. per 1,000 for every £1 per ton above or below £76 received by the contractor for brass scrap was inserted, and similarly a variant of ·32d. for every £1 per ton above or below £82 for cupro-nickel scrap.[3] In the Rudge-Whitworth contract of March, 1917, and the Birmingham Metal and Munitions Company contract of June, 1917, scrap clauses of a much simpler nature appear, the clause simply stating that in the event of the prices payable for scrap varying from those payable on a certain fixed date, the price for cartridges shall be varied to a proportionate extent.[4]

[1] 94/C/990.
[2] 94/C/1606 ; /424.
[3] 94/C/9907 ; /2081.
[4] 94/C/5087. P.M./C/5438.

VIII. Financial Results.

Such complicated financial arrangements could be justified only on the ground that they were the most economical under the circumstances. Proof of this point involves a detailed study of the actual cost of manufacture of the principal types of ammunition by the leading trade firms, and a comparison of it with the prices actually paid by the Ministry when adjustments under the sliding scale had been made. In theory the difference should amount to about 7½ per cent. on the cost price, which was reckoned by the Ministry as a fair profit on the contract. As figures for the actual cost of manufacture cannot be obtained, it is impossible to say whether theory and practice agreed. A comparison of the prices actually paid by the Ministry (where they can be obtained) with the corresponding figures for the Government Cartridge Factories, seems to show that trade prices were not unduly high. Thus, in November, 1917, the price of a leading Birmingham firm making 7·62 in. ammunition was 130/4 per 1,000 rounds, and that of a Yorkshire firm 133/6.[1] In September, 1917, when the first costs were available for this type of ammunition in Government Cartridge Factories, G.C.F. 1's costs were 136/3, and they were reduced to 119/7 in January, 1918. G.C.F. 3's costs in November, 1917, were 115/11.[2] Another example may be taken from 303 in. in July, 1918, when the costs of G.C.F. 1's were 117/6 per 1,000 rounds, and those of the biggest Birmingham firm were 139/1.[3] At first sight there appears considerable discrepancy between trade prices and the lowest costs of the G.C.F.'s, but it must be remembered that the latter were new factories, equipped with every possible device for economy, and using a large percentage of semi-skilled and unskilled tool room labour. Their oncost and labour cost would therefore be considerably less than those of the older factories, and when this is taken into account, the trade prices compare favourably with those of the G.C.F's. On the whole it seems safe to say that in the abnormal circumstances the system of payment worked out by experience represented the maximum of economy attainable by the Government, consistent with obtaining the active co-operation of the trade, without which the maintenance of supply would have been impossible.

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[1] D.D.G.E/E.M.2/1337. [2] See p. 66. [3] Sec./Gen./2239.

CHAPTER X.

REVIEW OF MANUFACTURING DIFFICULTIES.

I. Difficulties Affecting all Manufacturers.

All makers of small arms ammunition experienced the difficulties which resulted from the shortage of raw and semi-manufactured materials, such as aluminium and cartridge nickel strip, quite early in 1916, copper at the end of 1916, and lead in 1917, from the failure of building and machinery contractors to fulfil their promises of delivery, and from the congestion of the labour market. Typical of the difficulties encountered in increasing output are the experiences of the Birmingham Metal and Munitions Company and the King's Norton Company in the spring of 1915. Buildings for the Birmingham Metal and Munitions Company, due for completion by October, 1915, were not finished till February, 1916, and plant which should have been fully delivered by September, 1915, was still without a single complete unit in February. The King's Norton Company, whose complete plant had been promised by the end of December, 1915, had only 24 machines delivered at that date. This firm seems to have suffered considerably from lack of skilled labour—probably a difficulty of all the firms situated in the Birmingham district, where competition for labour was tremendous. When negotiating with the War Office in 1915 for an increased output, Messrs. Kynoch stipulated that no workpeople must be taken away without their consent, and that the Government must be prepared to supply men if the firm could not obtain sufficient labour by their own efforts. At the same date Messrs. Greenwood & Batley, of Leeds, put forward the difficulty of procuring suitable labour as one reason for refusing to undertake any further increase in output. The impossibility of getting and retaining enough labour was again put forward at the beginning of 1916 by the firm as a reason for their poor output. They complained that as fast as they took girls and trained them, they were taken away by Woolwich Arsenal. Strikes were another difficulty which seems to have affected the output of this firm particularly, though all firms had to cope with them at one time or another.

Air raids were another periodical difficulty. In February, 1916, the outputs of the Birmingham Metal and Munitions Company, Kynoch, and the Arsenal were all decreased by air raids. Woolwich in particular suffered heavily, and the disorganisation which resulted from a raid or a warning may be judged from Woolwich figures. On the night shift of 24/25 September, 1917, only 27 per cent. of the employees in the ·303 in. and rifle grenade shops were present, and the output was only 174,000 cartridges as against the normal output of 975,000. The night of Sunday, 30 September, was even worse.

Though 27½ per cent. of the hands in the same shops were at work, the actual output was 46,000 rifle grenade cartridges and no ·303 in. at all. 7·62 mm. output suffered equally, 74,000 only as against a normal output of 300,000 being produced.[1] The fact that several of the small arms ammunition firms had their loading shops at Abbey Wood increased the general reduction of output due to this cause.

II. Organisation of Different Firms.

Where output was not satisfactory, the Ministry offered advice with regard to organisation, suggesting changes of management and procedure. Especially was this the case with the smaller firms, for whom the rapid increase of output demanded meant a bigger strain on their organisation and resources.

A change of management was suggested in the case of one firm; in another case a factory was specially inspected. In the spring of 1916, when the Rudge-Whitworth company were getting their new small arms ammunition factory at Tyseley under way, the Ministry was always carefully watching them.

That the organisation at Kynoch's works was good may be deduced from the fact that the firm was the first to be turned to by the Ministry for help in obtaining supplies of a special type or special urgency. They were selected to provide the urgent supplies of 7·65 mm. for Belgium in the autumn of 1914; the firm shared with Woolwich the order for ·256 for Russia; they did more than any other trade firm to help in the matter of armour-piercing ammunition; they undertook the work of dealing with salvaged ammunition in 1917, and they gave a steady output of revolver ammunition, large calibre cartridges, ·22 in. rim fire cartridges, and components of every type and description. In fact, Messrs. Kynoch may be called the Woolwich of the trade, and all their multifarious activities were carried on without any undue strain on their organisation. In March, 1918, it was stated by the Supply Department that Messrs. Kynoch, Ltd., was the "most efficient of the S.A.A. contractors."[2]

III. Deliveries.

Messrs. Kynoch increased their output far more than any other firm (from 3,500,000 weekly in April, 1915, to 25,000,000 weekly by the end of 1916); they more nearly attained the output estimated by the Ministry than any other firm; in May and June of 1916, and during the critical period of 1918, they were exceeding it. When the King's Norton Company got over their initial difficulties they also succeeded in attaining a good output. Before their change over to 6·5 in May, 1917, and again in 1918, they were considerably exceeding their estimates. The Birmingham Metal and Munitions Company's deliveries did not realise expectations, *e.g.*, in September, 1916, they only gave a delivery of 43,000,000 as against an estimate of 70,000,000; in October, 37,000,000 instead of 60,000,000; in November, 32,000,000 instead of 62,000,000; and in December,

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[1] D.D.G.E./EM2/529. [2] D.D.G.E./E.M. 2/1434.

32,000,000 instead of 77,000,000. Deliveries improved somewhat in 1917, and even more in 1918; but even so, their average was considerably lower than the estimates. Messrs. Greenwood & Batley were also behind with their deliveries, and the smaller firms were all of them very slow in attaining their contract rate.[1] In considering the question of deliveries, it must, however, be remembered that the output of most firms was very considerably affected at different times by orders for special types of ammunition, which, owing to the difficulty of manufacture, hindered the production of the normal type far more than it would appear from the relative quantities ordered.

IV. Quality of Ammunition.

The King's Norton Metal Company were conspicuous for the high quality of the ammunition they manufactured. Early in 1916 it was stated by the supply department that this firm produced the best cartridges on the market, and again at the end of 1917 the Contracts Department said, "This contractor produces a better cartridge at a lower price than any of the other makers."[2] When the demand for special ·303 in. Mark VII for the Royal Flying Corps was put forward in 1917, a demand which involved not so much novelty in manufacture as special care and accuracy, the King's Norton Company were asked to undertake it, and when the demand outgrew the firm's capacity Kynoch was the next firm to whom an order was given.

In 1918 the King's Norton Company were the contractors for Red Label S.P.G. and Buckingham cartridges also.[3] Eley Brothers seem also to have produced a very good cartridge, and they were given a large number of orders for components for special types of ammunition. They undertook the manufacture of the war heads and bullets for the Pomeroy ammunition, work which involved considerable delicacy of manufacture on account of the necessity of fitting the war heads accurately into the bullet.

V. Costs as a Standard of Efficiency.

The cost of manufacture by the different makers is not a reliable guide for testing efficiency. It is true that economical manufacture lowered costs, since it meant less scrap, less labour and less oncost; but, on the other hand, so many other factors entered in that the position as regards costs becomes exceedingly complex. Prices were considerably modified by Government advances, and it cannot be argued that because one firm's price was 95s. per 1,000 and that of another firm 125s. per 1,000 the former were the more efficient manufacturers. The latter firm had received no advances from the Government and their price therefore took account of their capital expenditure, while the price of 95s. was based on the fact that the Government had advanced the money for the extensions and was also modified by the sliding scale attached to it, which brought the real

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[1] D.D.G.E./EM2/529. [2] 94/C/220. [3] D.D.G.E./EM2/529.

price up to approximately 118s. in the spring of 1917. Even if we disregard contract price and judge only by the actual cost as revealed by Ministry investigations, the problem is not much simplified, for there were various factors other than efficiency affecting costs. One of these was the source of supply for strip. Firms who had their own rolling mills were able to get their strip much more cheaply than a firm who bought all their metal. The price of labour was another factor over which the maker had no control. This is clearly shown in the case of Woolwich, where the cost of labour in March, 1918, was 36s. 4d. per 1,000 cartridges as compared with 20s. 8d. for G.C.F.1. This was due, as the Chief Superintendent of Ordnance Factories explained, to the pre-war policy of excluding female labour and of paying high piece-work prices, a policy which could not be altered when the output was so largely increased without breaking Government pledges. It was further explained by the scattered position of the factories and the heavy oncost due to the scheme of pension and gratuities, hospital and medical attendance, etc., which were integral parts of the Arsenal system.[1] Charges of this kind swell the costs of manufacture unavoidably and render any real comparison of costs misleading. Another factor which affected costs very considerably was the amount of dislocation due to firms undertaking special experimental work at the request of the Ministry. In October, 1916, the actual cost per 1,000 cartridges made by one firm was 150s., an extremely high price, but due to the fact that the whole of the experimental staff at that date was working on tracer bullets.[2] All these different factors make the question of costs a very complex one, and dangerous to use as a standard of efficiency.

VI. Efficiency at Woolwich.

When the Ministry was first constituted, the organisation of Woolwich was subjected to a considerable amount of criticism from the Supply Department. The gist of the complaint was that Woolwich required about three times the number of machines to get the same output as the three trade firms with the largest output and that there was a great deal of waste in the processes of manufacture. It was considered that the output should be largely increased beyond the promises of the Chief Superintendent of Ordnance Factories, and that this could be done by balancing the plant, working the machines at greater speed and introducing women's labour instead of the boy labour in use at the Arsenal. As a result of a detailed comparison made by the Supply Department between Woolwich manufacture and the methods of the trade, C.M.2 stated in October, 1915, that the information obtained " points to the necessity for the best man obtainable being put in sole charge of the Cartridge Factory with a free hand to do whatever is necessary to produce adequate results."[3]

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[1] D.D.G.E./EM2/1454.

[2] 94 Firms R/325.

[3] Mr. Gibson's Report to Sir F. Black, February, 1916. (C.R./4501).

The subject was apparently dropped in 1916, when departmental changes were made at the Ministry and Woolwich output was left entirely to the Chief Superintendent of Ordnance Factories. However much of truth there may have been in the statement that a bigger output might have been attained, the figures show that Woolwich did better on the whole than any of the trade firms in fulfilling their promises. The conservative estimate of 9,000,000 weekly at the beginning of 1916 was almost achieved in February, when the output was 8,870,000. In April E.M.2 stated that "Woolwich is the only large output which approaches expectations."[1] In 1918 the Arsenal, like the best trade firms, largely exceeded its estimated output.[2] On the whole Woolwich throughout took the first place as regards fulfilment of its promises, and this was done while a great deal of time and experiment was being given to special types of ammunition. More than that of any of the trade firms the normal output was disturbed by urgent demands for an output of tracer and armour-piercing ammunition, and the attention of the expert staff was largely engrossed by the developments in design as well as the difficulties of manufacture of these types. On the other hand, as regards cost, Woolwich ammunition compared badly with the trade. In March, 1918, the Chief Superintendent of Ordnance Factories estimated that the cost of ·303 in. Mark VII per 1,000 rounds was 164s. 6½d., while one trade factory's cost at the same date was 116s. 8d. But, as has been stated, the heavy costs at Woolwich were due to conditions inherited from pre-war days, to remedy which no attempt could be made while the greatest possible output was the pre-eminent consideration.

VII. Dilution of Labour.

The attitude towards the introduction of women's labour varied considerably. In this respect very varying conditions are to be found. At one end of the scale is Woolwich, where before September, 1915, no women were employed, and where, even when necessity at last forced the Arsenal to utilise them, progress was very slow. At the other end are the Government Cartridge Factories, started on the assumption that women's labour should be employed wherever possible, and having the smallest percentage of skilled male labour of any small arms ammunition works in the United Kingdom. The fact that at either end of the scale are Government factories is eloquent testimony of the difference the war made in this respect. The pre-war Government factory, hedged about by traditions and prejudices, only slowly adjusted itself to the altered conditions, while the Government Cartridge Factories, built under the influence of new ideas, soon showed the private firms that their fears as to inefficiency and reduction in output through dilution had no foundation in fact.

Private firms varied considerably in their willingness to undertake dilution. On the whole, they were opposed to it, objecting naturally to the temporary dislocation of work consequent upon the change, and fearing the attitude of the men workers towards the introduction of women. The figures of dilution given in the dilution reports of the different firms are of little value in judging the extent of dilution taking place in the small arms ammunition industry in particular, since

[1] D.D.G.E./EM2/529.

[2] See Appendix II.

practically all the firms had other departments besides their small arms ammunition shops and the figures given apply to the whole works. But in a special report on dilution in small arms cartridge and bullet manufacture made in June, 1918, the percentages of skilled labour and women and boy labour are given for this work alone. The position with regard to the case and bullet shops was as follows :—

Firm.	Men.		Women and Boys.
	Skilled.	Semi and Unskilled.	
Eley Brothers	4 per cent.	11 per cent.	85 per cent.
King's Norton	4 ,,	21 ,,	75 ,,
Birmingham Metal and Munitions Company	11 ,,	8 ,,	81 ,,
Kynoch	13 ,,	12 ,,	75 ,,

In the tool rooms, the percentages were :—

Firm.	Men.		Women and Boys.
	Skilled.	Semi and Unskilled.	
Eley Brothers	50 per cent.	49 per cent.	1 per cent.[1]
King's Norton	61 ,,	—	39 ,,
Kynoch	67 ,,	—	33 ,,
Birmingham Metal and Munitions Company	72 ,,	4 ,,	24 ,, [2]

Thus, in the case and bullet shops, dilution seems generally to have been very fairly practised, but there is a considerable difference between the results achieved in the tool rooms. This is where the real test of the use made of women's labour lies, since much of the work in the case and bullet shops was repetition work. Neither Messrs. Greenwood & Batley nor Messrs. Rudge-Whitworth appear in the small arms ammunition report. In the case of the former, women were being employed in the case and bullet shops in December, 1916, and it was reported that the number of skilled hands was low in proportion to the output. The latter were employing 1,323 women to 481 men in their Tyseley factory in the middle of 1917, and their attitude towards dilution was reported to be good. Progress in dilution was undoubtedly made by the trade firms, but it was late in beginning and tentative in character at first. It was the pressure of necessity and the experience of the Government Cartridge Factories that led the trade firms to practise it to any extent, but in view of the difficulties attendant upon dilution in a highly skilled industry, they can hardly be blamed for this attitude, and some firms indeed achieved very considerable results when once they were won over to the idea of dilution.

[1] Limited by arrangement with the Amalgamated Society of Engineers. See p. 68.
[2] (Printed) *Weekly Report*, No. 148, IX (29 June, 1918).

APPENDICES.

APPENDIX I.

Principal Demands on the Ministry from August, 1915, to November, 1918.

(*a*) Requirements of the War Office.

(Figures in Thousands.)

Note.—The table shows demands only: it does not follow that they were always supplied in full. Certainly in the case of tracer and armour-piercing ammunition supplies did not at first meet requirements. Changes are shown in the month when the War Office first demanded them, though in some cases the change did not actually take place till later.

Date.	·303 in. Mk. VII.	·303 in. Mk. VII. Special.	A.P.	Buckingham.	S.P.K.	S.P.G.	P.S.A.	R.T.S.	Pistol Ammunition.		
									Webley Mk. II.[4]	·45 in. Colt Automatic.	·455 in. Automatic.
1915.											
August	132,000	—	—	—	—	—	—	—	2,700	—	—
September	150,000	—	—	—	—	—	—	—	2,700	—	—
October	150,000	—	—	—	—	—	—	—	2,700	—	—
November	167,000	—	—	—	—	—	—	—	2,700	—	—
December	217,000	—	—	560 (Flame Tracer)	—	—	—	—	2,700	—	—
1916.											
January	234,000	—	—	—	—	—	—	—	2,700	—	—
February	250,000	—	—	—	—	—	—	—	2,700	—	—
March	266,000	—	—	—	—	—	—	—	3,000 (Total—then cancellation)	—	—
April	282,000	—	—	—	—	—	—	—	—	—	—
May	298,000	—	500 (stock to be built up)	1,000	—	—	—	—	—	—	—

June	315,000	—	—	1,000	—	—	—	—	—	—	—
July	200,000[1]	—	—	—	6,000	—	—	—	2,000	—	—
August	200,000	—	—	—	6,000	—	—	—	2,000	—	—
September	200,000	—	—	100	6,000	—	—	—	2,000	—	—
October	200,000	—	—	100	6,000	—	—	—	2,000	—	—
November	130,000	—	—	100	6,000	—	—	—	2,000	—	—
December	130,000	—	—	100	6,000	—	—	—	2,000	—	—
1917.											
January	Suspension due to accumulated Stock	—	500	110	6,000	—	—	—	2,000	—	—
February		—	650	75	6,000	—	—	—	2,000	—	—
March		—	—	50	6,000	—	5,000 (Total)	—	2,000	—	—
April		—	—	50	6,000	—	—	—	2,000	—	—
May	150,000	—	—	100	6,000	—	—	—	3,800	—	—
June	110,000	—	—	100	—	2,000	—	—	3,800	—	—
July	130,000	—	—	100	—	2,000	—	—	3,800	—	—
August	130,000	—[2]	625	100	—	2,000	—[3]	—	3,800	608[5]	50[6]
September	130,000	—[2]	500O (Total) 20S	100	—	2,000	—	—	3,800	100	50
October	150,000	2,000	500O 20S	100	—	2,000	5,000 (Total)	—	3,800	100	50
November	150,000	2,000	500O 20S	100	—	2,000	—	—	3,800	100	75
December	185,000	3,000	750O 750S	100	—	2,000	—	—	3,800	100	75

[1] In September, 1915, the War Office stated that from July, 1916, onwards requirements would be 300,000,000, but before this demand came into operation they reduced it to 200,000,000.

[2] A naval demand for 250,000 is not shown. This was subsequently included in the War Office demand.

[3] A naval demand for 60,000 is not shown.

[4] The requirements for Webley Mark II are given in weekly figures by the War Office. For purposes of comparison they have been estimated on a basis of four weeks three days to the month.

[5] O=Ordinary. S=Special.

[6] Stock of 50,000 also to be built up at home.

APPENDIX I—*continued.*

(Figures in thousands.)

Date.	·303 in. Mk. VII.	·303 in. Mk. VII. Special.	A.P.	Buckingham.	S.P.K.	S.P.G.	P.S.A.	R.T.S.	Pistol Ammunition.		
									Webley Mk. II.	·45 in. Colt Automatic.	·455 in. Automatic.
1918.[1]											
January	185,000	3,000	750O 750S	100	—	2,500	—	—	3,800	100	75
February	185,000	4,500	800O 1,200S	600	—	2,000O 2,500S	—	—	3,800	100	75
March	230,000	4,500	800O 1,200S	600	—	2,000O 2,500S	—	20 +500 reserve.	3,800	100	75
April	550,000 (2 demands)	6,000	800O 1,200S	600	—	2,000O 2,500S	—	20	3,800	100	75
May	312,000	9,500	800O 1,200S	750	—	2,000O 2,500S	—	40	3,800	100	100
June	312,000	9,500	800O 1,200S	750	—	2,000O 2,500S	—	40	3,800	100	100
July	312,000	9,500	2,300O 800S	750	—	2,000O 2,000S	—	40	3,800	100	100
August	300,000	9,500	2,300O 1,600S	575	—	2,000O 2,000S	—	40	3,800	100	150
September	300,000	9,500	2,300O 1,600S	575	—	2,300O 2,000S	—	20 +2,000 reserve.	3,800	100	150
October	300,000	9,500	2,300O 1,600S	575	—	2,300O 2,000S	—	20	3,800	100	150
November	250,000	9,500	2,300O 1,600S	575	—	2,300O 2,000S	—	20	3,800	100	300

[1] Air Ministry requirements are included with those of the War Office in 1918.

APPENDIX I—*continued.*

(*b*) Requirements of the Allies.

(Figures in thousands.)

Date.	·303 in. Mk. VII.		Bucking-ham. (France)	S.P.G. (France)	·256 in. Japanese (Russia)	7·62mm. (Russia)	6·5 mm. (Roumania)	7·65 mm. (Belgium)
1916.								
January ..	—		—	—	—	—	—	—
February ..	—		—	—	—	—	—	—
March ..	—		—	—	15,000	—	—	—
April ..	—		—	—	25,000	—	—	—
May ..	—		—	—	45,000	—	—	—
June ..	—		—	—	45,000	—	—	—
July ..	113,000	Russia and Roumania.	—	—	45,000	52,000	13,000	—
August ..	113,000		—	—	45,000	78,000	13,000	—
September ..	113,000		—	—	45,000	78,000	13,000	—
October ..	113,000		—	—	45,000	78,000	13,000	—
November ..	113,000		—	—	45,000	78,000	13,000	—
December ..	113,000		—	—	45,000	143,000	13,000	—
1917.								
January ..	113,000		25 (total)	100 (total)	40,000	203,000	13,000	—
February ..	113,000		—	—	40,000	203,000	13,000	—
March ..	113,000		75	300	40,000	203,000	13,000	50,000 (total)
April ..	113,000		75	300	40,000	203,000	13,000	—
May ..	—		75	300	—	203,000	6,000	—
June ..	—		75	300	—	203,000	6,000	—
July ..	—		75	300	—	203,000	6,000	—
August ..	—		75	300	—	203,000	6,000	—
September ..	—		75	300	—	203,000	6,000	—
October ..	—		500	2,000	—	150,000	6,000	—
November ..	—		500	2,000	—	150,000	—	—
December ..	—		500	2,000	—	—	—	—
1918.								
January ..	150	Italy.	500	2,000	—	—	—	32,000 (total—to follow on completion of 50,000 ordered in March 1917)
February ..	200		500	2,000	—	—	—	
March ..	200		500	2,000	—	—	—	
April ..	300		500[1]	2,000[1]	—	—	—	
May ..	300		1,000	1,900	—	—	—	
June ..	300		1,000	1,900	—	—	—	
July ..	400		1,000	1,900	—	—	—	
August ..	400		1,000	1,900	—	—	—	—
September ..	400		1,000	1,900	—	—	—	—
October ..	400		1,000	1,900	—	—	—	—
November ..	400		1,000	1,900	—	—	—	—

[1] From April, 1918, there was a monthly demand from America for 500,000 bullets made up of Buckingham S.P.G. and A.P. This is not shown in the table.

APPENDIX II.

Factory Output of Small Arms Ammunition.

(*a*) ·303 in. Mark VII.

(Figures in Thousands.)

Date.	Royal Ordnance Factory.	Birmingham Metal & Munitions Co.	Nobel's.	Eley Brothers.	King's Norton Metal Co.	Greenwood & Batley	Kynoch.	Rudge-Whitworth.	G.C.F.1.	G.C.F.3.	Total from British Sources. Monthly.	Total from British Sources. Quarterly.	Total from U.S.A. Quarterly.	Grand Total Quarterly.
15Aug.,'14, to 26 June,'15	94,559	103,793	*	33,381	55,553	45,945	110,161	—	—	—	443,372	443,372	58,223	501,595
1915.														
July	24,968	18,330	3,267	6,017	11,200	10,150	35,000	—	—	—	108,932			
August	20,935	15,779	3,266	4,501	9,500	13,500	28,400	52	—	—	95,933	317,099	69,800	386,899
September	23,721	19,689	3,518	4,186	13,600	15,300	31,800	420	—	—	112,234			
October	31,156	29,346	5,527	6,267	19,700	18,000	49,652	1,500	—	—	161,148			
November	27,388	23,722	5,018	5,446	15,079	14,400	38,904	1,658	—	—	131,615	424,696	134,039	558,735
December	24,040	24,471	3,769	6,023	14,010	17,100	40,600	1,920	—	—	131,933			
1916.														
January	47,204	34,455	5,035	7,447	17,520	20,400	41,900	2,520	—	—	176,481			
February	35,493	26,281	5,025	6,526	15,530	15,000	30,894	3,110	—	—	137,859	469,953	141,200	611,153
March	40,042	32,284	5,025	7,302	13,540	15,600	37,000	4,820	—	—	155,613			
April	43,208	40,710	5,528	8,780	14,040	21,600	46,000	6,170	—	—	186,036			
May	39,100	37,757	5,527	7,269	17,158	27,000	51,500	3,230	—	—	188,541	577,349	139,200	716,549
June	42,900	37,857	6,030	6,555	17,610	27,600	61,500	2,720	—	—	202,772			
July	50,550	54,265	7,537	10,601	22,613	36,600	75,500	13,240	—	—	270,906			
August	39,360	47,135	5,527	9,175	18,055	25,200	62,500	12,840	—	—	219,792	710,532	149,000	859,532
September	43,850	43,270	6,533	9,681	21,000	21,000	65,000	9,500	—	—	219,834			
October	37,600	37,144	6,029	8,793	19,040	28,800	68,000	8,250	—	—	213,656			
November	27,900	32,927	6,783	8,284	19,573	29,400	65,000	9,850	—	—	209,717	635,047	163,200	798,247
December	37,194	32,054	5,277	9,099	14,500	33,600	72,000	7,950	—	—	211,674			
1917.														
January	34,089	36,341	5,778	7,917	22,023	26,400	72,000	8,700	—	—	213,248			
February	15,354	28,891	5,276	8,972	19,156	31,800	69,000	8,150	—	—	186,599	583,739	93,062	676,801
March	13,848	36,592	6,029	8,938	19,135	29,400	60,500	9,450	—	—	183,892			
April	8,847	24,137	3,516	2,947	6,500	8,400	18 000	6,500	—	—	78,847			
May	7,898	28,481	4,522	1,141	1,000	1,000	2,000	8,400	—	—	54,442	219,821	4,402	224,223
June	23,904	40,709	6,029	709	2,500	781	1,500	10,400	—	—	86,532			
July	30,429	45,727	5,024	486	7,100	—	—	11,000	—	—	99,766			
August	35,815	34,638	502	—	4,605	—	—	8,250	—	—	83,810	318,609	—	318,609
September	40,927	52,641	408	57	8,800	—	17,000	15,200	—	—	135,033			
October	30,139	42,415	—	—	5,600	—	18,000	12,300	—	—	108,454			
November	37,091	40,298	—	—	5,227	—	21,500	11,000	—	—	115,116	354,231	—	354,231
December	45,392	38,662	—	—	4,507	—	31,000	6,350	—	4,750	130,661			

1918.															
January	40,108	23,000	—	—	5,000	—	63,000	5,753	—	7,250	144,111			
February	32,640	33,023	—	—	5,900	—	71,000	14,330	—	15,500	172,393	538,163	—	538,163
March ..	42,802	32,723	—	331	13,970	250	99,000	11,833	—	20,750	221,659			
April	51,209	25,254	—	666	15,556	12,878	101,650	9,609	16,934	23,250	267,006			
May	45,600	26,836	—	1,819	13,070	15,818	95,000	8,753	24,209	27,250	258,355	877,574	—	877,574
June	58,950	30,000	—	2,771	18,184	* 29,500	127,000	12,502	34,306	39,000	352,213			
July	33,050	26,000	—	1,712	10,694	25,403	96,500	9,780	28,815	30,750	262,704			
August	30,628	30,337	—	991	9,707	22,000	98,000	9,253	27,287	32,250	260,453	779,064	—	779,064
September	25,087	31,950	—	1,389	10,929	20,300	98,750	10,002	25,500	32,000	255,907			
October	21,400	34,000	—	1,326	10,900	19,000	93,500	9,754	31,250	32,500	253,630			
November	14,050	28,000	—	1,178	10,741	19,500	81,600	6,725	26,184	25,000	212,978	529,481	—	529,481
December	4,750	6,000	—	792	2,805	6,400	27,000	2,648	3,978	8,500	62,873			
Total	1,465,175	1,477,924	131,305	209,455	582,430	705,025	2,373,811	316,392	218,463	298,750	7,778,730	7,778,730	952,126	8,730,856

* Output included under Birmingham Metal and Munitions Company.

(*b*) Principal Special Types.

(Figures in Thousands.)

Date.	·303 in. Mk. VI.	·303 in. Mk. VII Salvaged	·303 in. Mk. VII (2nd Quality).	·303 in. Mk. VII Special.	·303 in. A.P.	·303 in. Buckingham (Cartridges).	·303 in. P.S.A.	·303 in. S.P.K. & S.P.G. (Cartridges).	R.T.S.	·22 in. Rim Fire.	Revolver Mk. II.	Pistol Automatic.	·256mm. Japanese	7·62mm.	6·5 mm.	7·65mm.
1915	2,400	—	—	—	—	—	—	—	—	32,080	7,327	—	—	—	—	—
1916.																
January ..	3,400	—	—	—	—	—	—	—	—	1,600	1,855	—	—	—	—	—
February ..	800	—	—	—	—	—	—	—	—	3,000	1,055	—	5,000	—	—	—
March	600	—	—	—	—	—	—	—	—	2	1,457	—	12,000	—	—	—
April	1,000	—	—	—	—	—	—	—	—	1,540	755	—	14,100	—	—	—
May	2,200	—	—	—	—	—	—	—	—	1,500	255	—	20,472	—	—	—
June	2,600	—	—	—	—	—	—	—	—	1,000	204	—	28,952	—	—	—
July	6,200	—	—	—	—	—	—	—	—	500	255	—	35,456	—	—	—
August	2,200	—	—	—	—	—	—	—	—	—	51	—	31,711	—	—	—
September ..	1,354	—	—	—	—	71	25	31	—	—	—	—	46,370	—	—	—
October	—	—	—	—	40	97	194	627	—	—	1,200	—	32,400	—	—	—
November ..	—	—	—	—	50	233	154	1,540	—	—	1,306	—	39,420	—	—	—
December ..	—	—	—	—	120	190	152	1,727	—	—	518	—	38,658	—	—	—

APPENDIX II.—*continued.*

Factory Output of Small Arms Ammunition.

(*b*) PRINCIPAL SPECIAL TYPES.—*continued.*

(Figures in Thousands.)

Date.	·303 in. Mk. VI.	·303 in. Mk. VII Salvaged	·303 in. Mk. VII (2nd Quality).	·303 in. Mk. VII Special.	·303 in. A.P.	·303 in. Buckingham (Cartridges).	·303 in. P.S.A.	·303 in. S.P.K. & S.P.G. (Cartridges).	R.T.S.	·22 in. Rim Fire.	Revolver Mk. II.	Pistol Automatic.	·256mm. Japanese	7·62 mm	6·5 mm.	7·65mm.
1917.																
January ..	—	—	—	—	190	99	36	2,072	—	—	1,753	—	38,890	600	—	—
February ..	—	—	—	—	—	85	30	2,487	—	—	1,225	—	41,524	3,377	400	—
March	—	—	—	—	170	—	75	4,561	—	—	2,763	—	48,111	34,711	3,800	—
April	—	—	—	—	423	—	64	3,646	—	—	2,854	5	29,565	43,763	4,800	—
May	—	—	—	—	123	—	37	2,689	—	—	2,788	8	31,582	96,035	1,500	—
June	—	—	—	1,501	211	37	240	3,503	—	—	3,736	80	29,906	133,770	2,950	—
July	—	—	—	1,500	398	77	268	2,037	—	—	3,041	60	19,000	151,375	2,500	—
August	—	—	—	2,317	447	132	333	1,381	—	—	2,486	20	14,000	117,810	4,000	—
September ..	—	—	—	2,437	854	139	509	2,383	—	—	4,497	120	2,030	214,865	8,000	562
October	—	—	—	2,000	785	100	219	1,681	—	—	3,247	12	—	175,883	5,500	2,752
November ..	—	—	—	1,805	992	73	151	982	5	—	3,398	73	—	171,047	5,524	3,903
December ..	—	—	—	2,401	919	73	200	1,174	10	—	3,803	49	—	117,720	8,000	3,753
1918.																
January ..	—	—	—	3,000	1,109	175	492	1,402	18	—	3,915	124	—	92,950	7,500	2,002
February ..	—	—	—	5,170	1,533	250	296	2,043	14	—	4,122	273	—	71,000	5,000	5,000
March	—	—	—	9,080	2,532	823	324	2,380	101	182	5,067	131	—	30,593	1,030	3,002
April	—	13,440	1,000	10,550	1,476	698	358	3,448	89	1,950	4,389	72	—	2,359	—	4,003
May	—	16,345	5,630	9,325	1,129	751	279	3,113	132	4,225	3,618	138	—	—	—	4,000
June	—	19,332	11,310	9,250	976	927	970	4,750	41	5,701	4,600	196	—	—	—	3,000
July	—	19,744	6,436	12,294	1,751	915	864	4,218	44	4,844	2,603	203	—	—	—	4,500
August	—	17,660	10,060	11,487	2,865	974	522	4,165	76	6,388	3,557	156	—	—	—	1,500
September ..	—	16,860	10,300	13,305	2,718	1,076	923	3,993	15	7,763	3,651	172	—	—	—	6,000
October	—	15,468	11,378	14,500	1,783	942	756	3,923	29	5,454	3,660	150	—	—	—	5,000
November ..	—	13,824	14,658	15,260	1,192	264	724	3,875	—	7,688	3,000	354	—	—	—	4,001
December ..	—	2,880	7,307	4,350	384	625	448	1,908	20	2,622	1,768	217	—	—	—	5,006
Total ..	22,154	135,553	78,079	131,531	25,170	9,826	10,643	72,029	594	88,039	83,075	2,613	558,947	1,457,858	60,504	57,984

GRAND TOTAL OF SPECIAL TYPES 2,794,599.

APPENDIX III.

Acceptances of Small Arms Ammunition.

(Figures in thousands.)

Date.	·303 in. Mk. VII* (British).	·303 in. Mk. VII (American).	·303 in. Mk. VI (American).	·256 in. Japanese	7·62mm.	6·5mm.
1914.						
August	6,960	—	—	—	—	—
September	31,970	—	—	—	—	—
October	20,750	—	2,190	—	—	—
November	25,600	—	8,190	—	—	—
December	34,320	1,700	5,400	—	—	—
			3,510			
1915.						
January	47,570	1,790	470	—	—	—
February	46,720	2,500	—	—	—	—
March	63,220	3,000	—	—	—	—
April	53,600	8,400	1,200	—	—	—
May	62,640	18,580	—	—	—	—
June	68,010	7,500	1,390	—	—	—
July	112,150	25,700	1,790	—	—	—
August	102,620	12,340	1,300	—	—	—
September	156,200	20,740	2,780	—	—	—
October	84,060	22,660	5,350	—	—	—
November	126,890	21,220	4,550	—	—	—
December	143,620	11,420	1,640	—	—	—
1916.						
January	134,980	17,570	2,060	—	—	—
February	134,090	28,250	2,120	—	—	—
March	185,760	28,970	2,300	—	—	—
April	145,550	8,990	1,710	—	—	—
May	218,730	76,040	2,440	—	—	—
June	185,100	66,210	1,400	—	—	—
July	198,500	37,550	2,300	2,710	—	—
August	257,650	53,680	4,760	12,100	—	—
September	177,780	48,900	2,300	17,650	—	—
October	170,450	78,710	970	12,520	—	—
November	244,290	61,970	1,200	14,260	—	—
December	157,590	21,840	1,140	5,530	—	—
1917.						
January	193,830	22,800	—	13,920	—	—
February	199,700	19,100	—	20,320	—	—
March	197,060	7,900	—	71,980	3,600	—
April	101,030	19,700	—	32,050	26,590	—
May	68,160	45,000	—	33,820	68,620	—
June	63,500	39,000	—	21,790	113,210	4,180
July	72,400	1,700	—	22,790	115,190	8,200
August	89,400	—	—	12,800	127,030	3,120
September	116,000	—	—	13,700	183,720	4,070
October	91,900	12,000	—	2,030	170,700	6,600
November	122,400	1,700	—	—	169,700	5,940
December	132,140	6,300	—	—	131,190	7,280
Carried forward ..	4,844,890	861,430	64,460	309,970	1,109,550	39,390

* Includes Special and Second Quality ·303 in. Mark VII.

APPENDIX III—*continued.*

Acceptances of Small Arms Ammunition.

(Figures in thousands.)

Date.	·303 in. Mk. VII* (British).	·303 in. Mk. VII (American).	·303 in. Mk. VI (American).	·256 in. Japanese	7·62mm.	6·5mm.
Brought forward ..	4,844,890	861,430	64,460	309,970	1,109,550	39,390
1918.						
January	151,700	270	—	—	126,250	5,620
February	140,000	—	—	—	67,140	5,090
March	148,400	—	—	—	44,590	2,550
April	280,700	—	—	—	10,830	3,290
May	267,800	—	—	—	11,160	—
June	285,300	—	—	—	12,440	—
July	220,000	—	—	—	6,510	—
August	241,800	—	—	—	360	—
September	244,300	—	—	—	—	—
October	320,700	—	—	—	—	—
November	151,500	—	—	—	—	—
December	61,400	—	—	—	—	—
Total	7,358,490	861,700	64,460	309,970	1,388,830	55,940

* Includes Special and Second Quality ·303 in. Mark VII.

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